San Diego LRT System: Ten Years of Design Lessons

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Ten years ago the San Diego light rail transit (LRT) system opened for business after 4 years of planning, design, and construction. The initial system included only the basics, a 15.9-mi (25.6-km) single-track line with three passing tracks operating at 20-min headways. The total vehicle fleet consisted of 14 light rail vehicles operating in two-car trains. Today the San Diego LRT system has undergone four separate expansions resulting in a doubling of the system to over 35 route-mi (56.3 km). Seven more mi (11.3 km) are under construction, with another 28 mi (45 km) in various stages of preliminary engineering and final design. By the year 2005 the overall system is expected to operate over 90 route-mi (144.8 km). Although the basic philosophy of low cost, high speed, and primarily at-grade is still the foundation of the design process, 10 years of design experience, together with changing socioeconomic conditions, have resulted in the design approach being modified to meet the needs of a rapidly expanding LRT system. Experience has taught lessons that have been incorporated in subsequent design efforts.

Ten years of expansion and operations have provided the San Diego light rail transit (LRT) system the opportunity to improve the design process based on experience. This process has undergone numerous modifications and refinements since its inception in 1978. However, the same basic philosophy that governed the original South Line design and construction is still used today. That philosophy was adopted by the Metropolitan Transit Development Board (MTDB) in its infancy in 1976 and is still MTDB's Board Policy No. 1 "Rail Transit Feasibility Principles (*1*)." This policy remains the backbone of MTDB's rail design efforts today. The principles contained within the policy include high-speed operation, low capital cost, primarily at-grade with exclusive right-of-way, low operating costs that farebox revenue attempts to meet, and, most importantly, use of service-proven equipment and materials.

Numerous design approaches could satisfy these basic principles. The approach selected for the South Line was developed on a bare-bones approach, offering single track with three separate passing trucks and simple, basic station amenities. However, this approach is no longer possible because of a variety of factors, including mandated state and federal regulations on seismic, air quality, and water quality conditions; varying socioeconomic needs; the MTDB and public being more demanding as the system expands; passengers expecting more amenities; and improved ride quality, security, and comfort. Thus the challenge has been to modify and improve MTDB's design approach yet still maintain the basic philosophy. The result has been a continual evaluation and updating of the basic design approach or design criteria to keep pace with these changing needs.

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LRT DESIGN CRITERIA

Fifteen years ago the MTDB considered doing something that no other city in the United States had done in more than 40 years, that was to construct an entirely new light rail system. This endeavor was the first such rail transit construction in Southern California since the streetcar days of the 1950s. The design approach used in the original design process relied upon a series of task design reports approved by the board at various workshops (*2,3,4*). When it was determined that MTDB would expand the system to the east (*5*), it was felt that a single document pulling together all the various task reports plus lessons learned from the South Line should be combined into one document. Thus in 1983 the MTDB directors adopted the San Diego Light Rail Transit East Urban Line Project Engineering Design Criteria (*6*). These criteria resulted in a very specific document related only to the East Urban Line extension. The document, therefore, addressed specific needs, such as how to redesign specific streets (i.e., Commercial Avenue) and how to handle joint freight and LRT use specific to certain shippers along that line. Future extensions, such as the Bayside Line (*7,8*), would also follow that format of revising the design criteria specifically for each new LRT extension.

However, as it became apparent that the system would continue to expand (see Figure 1), the idea of developing specific LRT design criteria for each extension was dropped in favor of developing a single set of criteria that would apply to all future San Diego LRT expansions. The goal of these newly revised LRT design criteria was primarily twofold. First, to standardize to the extent possible the design of future lines and, second, to leave the designer as much latitude as possible to address the unique aspects of each individual extension. These revised criteria were adopted by the MTDB directors on August 22, 1991 (*9*).

FACILITIES DESIGN

In reflecting over the many years of design, numerous things could have been done differently based upon today's knowledge. Although the goal of meeting the basic principles was reached successfully, lessons learned along the way should make the implementation of subsequent lines easier.

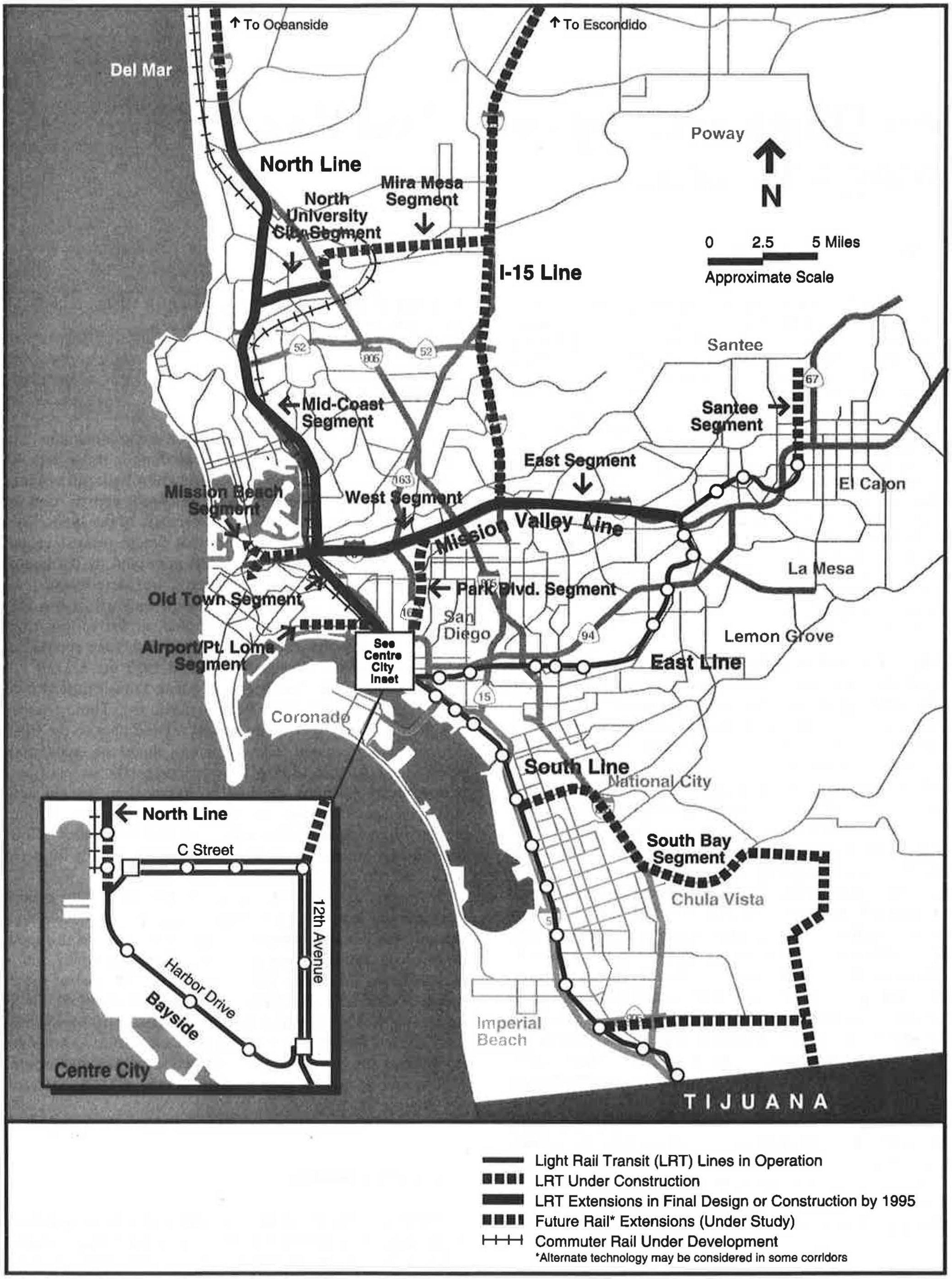

FIGURE 1 San Diego regional rail transit plan.

A prime example was the original decision to single-track the South Line and provide passing tracks where the trains were theoretically to meet. Although the concept and actual operation met with some success, a couple of important things were learned. The first, and probably most significant, was that the original design of the South Line did not contemplate double-tracking the line at a future date let alone under revenue service conditions. As a result, some major changes were necessary when it was decided that the South Line should be fully double-tracked.

A second major lesson from the South Line single-track operation was that, although such an operation does and can significantly lower the capital cost, a price is paid. Although detailed studies were performed in determining where the train meets would occur, actual operation did not follow theory. The result was that rather than operating 15-min headways on the South Line as originally planned, the operation had to be modified within weeks to accommodate a more realistic 20-min headway.

It was determined that one of the problems with precisely predicting train meets is that no two trolley operators are created equal—nor operate their trains the same. Because of these human differences, scheduled meets are almost impossible to predict accurately. However, the concept of single-track operations has not been abandoned totally by MTDB. An extension currently under construction, the Santee segment of the East Urban Line, will include a single track element near its terminal station.

For single-track operation to be successful, careful thought has to be given to the location of passing tracks, making sure to provide maximum operational flexibility whenever possible. For example, passing tracks should be extended through stations whenever possible. This feature allows a train to hold in a station while waiting for a single-track approach to clear. Also, passing tracks should be extended a significant distance beyond the theoretical meet point to allow maximum flexibility. On the East Urban Line, a 4-min allowance on either side of the scheduled meet point was provided.

Finally, and probably most importantly, any single-track operation should be designed ultimately to accommodate the second track. On the original South Line, there were significant problems with relocating substations, traction power poles, and other physical amenities because the original design did not take into account a future second track. This situation was corrected in the design of the East Urban Line. Although the East Urban Line was designed for single-track sections with passing tracks, the horizontal and verticle profile was also designed for both tracks. In fact the design went one step further, it included the construction of the embankment, crossovers instead of turnouts, and all associated civil improvements for the future second track. This initial construction avoided having to come back later under revenue operations to install major improvements close to an operating track. As it turned out, because of project cost savings, the East Urban Line was double-tracked prior to the beginning of revenue operations. Although single-track operations were never tested under this approach, the conversion to double-track during construction was certainly simplified by the process.

Another single-track feature that was a cost-saving measure was the use of existing structures. On the East Urban Line, three existing single-track bridges were used because double-tracking would have added more than $10 million to the overall project cost. In one instance, to provide maximum speed through the transition, a "gauntlet" was installed over one of the bridges. By installing the gauntlet, turnout facing points (determined to be the cause of the majority of the slowing) were eliminated. Instead only the frog was needed, allowing the operator to maintain a much higher speed through the transition area.

Another lesson was about the rail itself. Based on costs and the relative light weight of the vehicles, a consultant recommended that 90-lb (40.8-kg) rail be used. A heavier rail, such as 115-lb (52.2-kg) or 136-lb (61.7-kg), was thought to cost much more because of the significant increase in weight. Thus 90-lb (40.8-kg) rail was procured for the initial South Line operation. In preparation for the double-tracking of the South Line, it was learned that 90-lb (40.8-kg) rail was an odd size in little demand so the cost actually was the same as the heavier, more popular 115-lb (52.2-kg) rail. Because of the economies of scale, the 115-lb (52.2-kg) rail was acquired for essentially the same cost as that paid for the previous order of 90-lb (40.8-kg) rail. The special trackwork and rail have since been standardized to the more popular 115-lb (52.2-kg) rail. This standardization has not only resulted in significant cost savings, but relieved San Diego Trolley, Inc., maintenance personnel from having to stock as many spare parts (e.g., compromise joints, weld kits, etc.) and has generally simplified the overall maintenance process.

Finally there were various design options not originally taken advantage of either because they were technically not refined or were just too expensive at the time. However, in the past 10 years, the industry has made significant progress with new technology that still meets mandated service-proven requirements. An example would be the conversion from wood to concrete ties. Initially the low use of concrete ties in the industry resulted in a relatively high unit cost. Even though it was believed that concrete ties provided enhanced track stability, the high unit cost precluded their use. Now 10 years later, the cost of concrete ties has become more competitive with standard wood ties. As a result, MTDB today requires the use of concrete ties in all main-line applications in the design, except for special trackwork areas where the high cost of these special ties still dictates the use of wood ties.

Another example of cost and technology improvements changing MTDB's design approach would be the use of removable crossing material at grade crossings instead of cast-in-place concrete. Initially it was determined that cast-in-place concrete provided significant economic advantages over removal crossings, even though maintenance was more difficult. The initial evaluation was that the cast-in-place concrete provided a superior ride quality at a significantly lower cost. Again in the last 10 years significant gains have been in the use and technology of removable crossings, resulting in much lower costs. The cost and technology are now to the point where removable crossings justify consideration. Such consideration is especially applicable in open track areas where easily removable and replaceable crossings can reduce overall track maintenance costs. In paved street applications, cast-in-place concrete is still used by MTDB because of its lower cost, together with the less frequent track maintenance requirements for paved applications.

SYSTEMS DESIGN

In the systems area, lessons have been learned as well in the last 10 years. The first, and probably most significant, is the continued development of the traction power substations to be more economical, smaller, more powerful, and relatively easy to relocate. The desirability of these features rests with the resulting flexibility to interchange, relocate, and add new substations when necessary (*10*).

On the South Line, 11 low-capacity, 0.5-megawatt substations were installed. Their small size, 20 ft (6.1 m) by 23 ft (7.0 m), proved to be economical because they did not require significant additional land acquisition. When funds were granted for purchasing additional vehicles to handle growing patronage, 10 even smaller, 11 ft (3.4 m) by 25 ft (7.6 m), 1-megawatt substations were added to the system with relative ease and cost. These smaller, 1-megawatt substations can be easily picked up and moved by truck to wherever they are needed. This mobility has proven to be extremely beneficial because substations could be moved as necessary in the expansion of the overall system.

Additionally, the relatively small size makes it fairly easy to increase the capacity of the traction power system, in most cases without having to acquire additional right-of-way. For example, the overall LRT operation has gone from one line with two-car trains at 20-min headways in the downtown to two lines operating three-car trains with an average of 12 directional trains in the peak hour. Although this required a substantial increase in the traction power capacity in the downtown, the capacity was increased rather easily by adding units without having to acquire any new right-of-way. Likewise the same has happened in the yard area where the traction power capacity was designed to accommodate 14 vehicles. San Diego Trolley's fleet now has 71 vehicles with another 75 on order. The traction power capacity in the yard has been increased by substituting 1-megawatt substations in place of the 0.5-megawatt substations that were actually larger than their replacements.

When it comes to systems design, visual aesthetics have always been a significant design issue. One of the most significant problems in the public's eye is the visual impact of the overhead traction power system. This impact has been minimized in numerous ways in San Diego within the overall low-cost approach. Although the most visually appealing traction power system (i.e., an underground feeder system with a single contact wire) was used in the downtown area, this type of design has been avoided wherever possible because of the significantly higher overall cost.

On the South Line, outside of the downtown, a standard "full depth" catenary system is in place. The depth of the catenary ranges from 3.30 ft (1.11 m) to 1.10 ft (0.34 m). On the East Urban Line, because of the public's concern over visual impact, the designers developed a "low profile" catenary system. This system seemingly has a greater visual appeal than standard full depth catenary. Further the low profile design costs less than a single contact wire system in that it avoids the costly buried feeder system. The overall depth of this low profile catenary ranges from 1.50 ft (0.46 m) to 0.15 ft (0.05 m). The various cities along the East Urban Line agreed to allow this low profile system in their visually sensitive areas. The low profile has since become the standard design wherever visual concerns are identified.

Also, for aesthetic reasons, MTDB has gone to a standard traction power steel pole with the same outside diameter. For cost reasons on the original South Line, MTDB used a spun concrete pole. The outside diameter of the pole varied depending on the loads. Therefore on the South Line a number of different size poles give a cluttered, awkward look to the traction power system. Additionally those concrete poles were installed in a cast-in-place foundation. As a result, there was a complete loss of the traction power pole and foundation whenever any changes to the system were made. On the East Urban Line, MTDB used a standard cast-in-place foundation with a steel pole on a bolted foundation. Where a pole has failed, it has been a relatively simple procedure to replace it without losing the total investment in both the pole and foundation. The steel pole also allows the strength of the pole to be varied by changing the inside diameter, thus leaving a standard outside diameter and a uniform pole appearance throughout the system.

Proven technological advancements on the system's facilities have also resulted in improvements to the design approach. The most recent has been the addition of a train-to-wayside control system. This control system is being installed and, when complete, will provide for train location, automatic switching, electronic message boards at stations, and special signaling needs (i.e., nearside gate crossing hold-off and signal preemption where needed). The cost to install the system versus the overall benefits has become increasingly more attractive as the LRT operation grows. The current cost for installing this system on the existing 32 route-mi (51.5 km) is a little more than $1.5 million. This includes the cost to fit the vehicles with the vehicle transponders—a one-time investment that will not need to be duplicated on future extensions except for fitting any new vehicles.

Once the train-to-wayside control system is in operation, it will provide a relatively low-cost operational enhancement that will advise passengers at stations when trains are approaching and what route the train will be taking. Also, all switches will be thrown automatically for the specific train route, thus eliminating the basic route sequence controller. Additionally the implementation of the train-to-wayside control system will provide a low-cost train location system. When complete the location of all trains will be identified within the system automatically, eliminating the current reliance on radio communications. Finally the system will eliminate less reliable overhead mechanical switches that provide for vehicle traffic signal preemption and gate crossing hold-off control.

Alternatives to standard block signaling are also being explored by using train-to-wayside equipment. It is hoped that this approach will allow the existing train-to-wayside control system investment maximized by providing for simple LRT signaling on all future lines.

Finally, MTDB is in the midst of a sixth order of vehicles, with some significant changes to the unit's performance specifications. Although similar to the 71 existing vehicles in size and operation, a couple of key improvements have been made to the vehicle. Again in striving to meet the board's adopted principle of high speed, the new vehicles offer a power package that will provide approximately 25 percent more horsepower than the current vehicle. This added horsepower should provide for faster acceleration and a higher top-end speed. These power enhancements will become increasingly more important as the system expands into areas with steeper grades.

Additionally, the headways are at the point (i.e., 7.5-min on the South Line in the peak hours) where regenerative braking can start to provide significant power savings. Therefore all new vehicles will require regenerative braking. Thus savings will continue to increase as the system expands and headways are decreased.

CONCLUSIONS

The most important lessons learned by MTDB engineers in the past 10 years are those of standardization and incremental development. The more standardized the system is, the more economies of scale that can be gained along with reductions in inventory for spare parts and ease of maintenance. Standardization becomes more important as the system expands, allowing even greater cost savings as a result of economies of scale.

The incremental approach has provided the opportunity to refine the design approach based on experience. Lessons learned during the implementation and operation of one line were subsequently applied to new lines. This has resulted in the steady improvement of the system over the years.

Additionally it is important to keep an open, flexible mind during the design process. Too many restrictions on the designer tend to stifle their creativity and problem solving abilities. Keep in mind that LRT by definition is extremely flexible and adaptive to many different environments. What works in one place does not necessarily work in another.

Also no matter how long one has been involved in rail transit development or operations, there is always room for improvement and lessons to be learned. MTDB engineers have been able to enhance their designs and improve San Diego Trolley's cost efficiencies by learning from local experience. To this end MTDB has instituted a policy that once a job is complete, all change orders are evaluated to determine what items in future designs can be modified or changed to avoid repeating similar changes.

Lastly MTDB's experience has shown that innovation has its merits, but it is advisable to first prove that something works before implementing it systemwide. MTDB has had great success with a service-proven philosophy. However, care must be taken not to exclude all innovations. Therefore it has been MTDB's policy to encourage new ideas, but to make sure they are carefully reviewed and service proven either on other systems or by demonstration on an existing line.

In summary it is amazing to think back over all the changes that MTDB has made in its design approach over the last 10-plus years. Yet with all the changes, the overall basic philosophy has been maintained and, above all, the successful operation for which San Diego Trolley has become known has been retained.

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