Preliminary Geometric Design Analysis for Light Rail Transit

GARY A. WEINSTEIN, RAYMOND C. WILLIAMSON, AND
THOMAS M. WINTCH

During studies on the extension of the Guadalupe Corridor light rail transit (LRT) line, the City of Sunnyvale, California, was faced with the problem of entering an environmental review process with only one alignment option and very little information on LRT and city street geometrics or related potential impacts. City staff and consultants were able, within a very short time, to analyze, rank, and present to policy makers a large number of additional local LRT route options utilizing a technique of formalized design sketching. This paper describes preliminary geometric design for LRT, the design sketch formats that were used, and the two-step procedure in which they were applied. Observations and conclusions are also offered on the subject of conceptual geometrics and application of design sketching techniques to LRT planning and layout. Experience gained from the study demonstrates why all reasonable LRT route options should be considered in early planning and why the development of more detailed information on geometric design features is important in the early scoping stages of LRT projects. Quick and relatively inexpensive design sketch techniques make it possible to identify and evaluate alternatives and impacts earlier than otherwise would be possible, resulting in a better-understood project.

A RECENT PLANNING STUDY for light rail transit (LRT) in Sunnyvale, California, included the development and application of certain procedures for rapidly analyzing preliminary alignments and geometric design features

---

G. A. Weinstein, 2532 Hallmark Drive, Belmont, Calif. 94002. R. C. Williamson, City of Sunnyvale, P.O. Box 60607, Sunnyvale, Calif. 94088. T. M. Wintch, Bissell & Karn, Inc., 100 N. Milpitas Boulevard, Suite 160, Milpitas, Calif. 95035.

of alternative LRT lines. Some of the procedures were found to be especially useful.

Sunnyvale is a city with a population of about 115,000. It is situated 44 mi south of San Francisco and 10 mi northwest of San Jose. The electronics and aerospace industries came to Sunnyvale in the 1950s and the city continues to be a major center for high-technology industries. Because of its success in attracting employers, Sunnyvale faces an imbalance of jobs and housing. The city is seriously concerned about traffic problems, and some hope for relief is seen in a proposed extension of the existing Guadalupe Corridor LRT line that begins in San Jose and now ends within 1,500 ft of the Sunnyvale city limit.

This possible LRT line extension was included among other options in an alternatives analysis by the San Francisco Bay Area Metropolitan Transportation Commission (MTC). The MTC study was made for the Fremont-South Bay Corridor and included only one route alternative for extension of the Guadalupe Corridor LRT line into Sunnyvale (see Figure 1). When it was first proposed, very little detailed information was available to the city about the line or its impacts, and the city was faced with the problem of entering into the alternatives analysis/draft environmental impact statement (AA/DEIS) process without sufficient information. At the time of scoping, the single LRT route defined by the MTC provided only limited information about such features as alignment specifics, impacts on city street traffic, right-of-way width, reduction of parking, and landscaping requirements.

SUNNYVALE LRT PLANNING STUDY

The City of Sunnyvale was greatly interested in the LRT mode, but was uncertain about whether the one route proposed by the MTC was the best available. Although a subsequent environmental analysis would provide more detail, it would come too late to influence the initial selection of alternatives.

Sunnyvale therefore undertook its own preliminary study of possible LRT alignments within the city limits to review the proposed route, anticipate its impacts, and identify any additional local route options that might prove attractive. The initial work was to be completed on a very short schedule of about 1 month so that it would not delay the MTC process. Within that schedule city staff and consultants were able to develop, analyze, rank, and present to policy-makers a range of new local LRT route options, utilizing a technique of formalized, freehand design sketching. Using this technique, several new alignment options were shown to be feasible that might better address city objectives. These options were then submitted to the MTC and were included in the main AA/DEIS process.

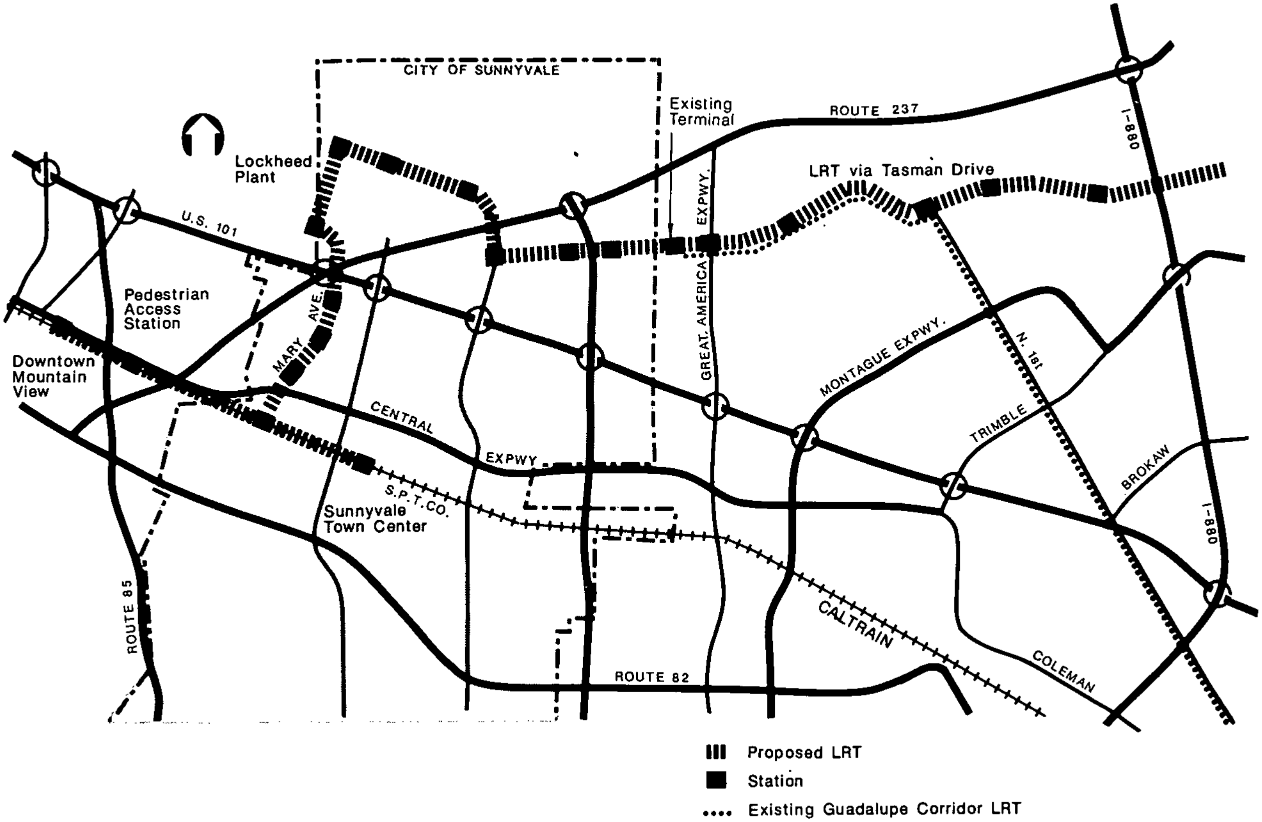


FIGURE 1 LRT routing through Sunnyvale as first proposed.

A major feature of the study was its early progress beyond a generalized concept of the route alignment, proceeding to develop a comprehensive preliminary geometric design for each alternative route. This proved important because the geometric configuration of the line is the key to defining environmental impacts such as right-of-way requirements, neighborhood noise and visual intrusion, traffic capacity, effect on landscaping and open space, extent of construction, etc. Furthermore, it was found that local impacts and costs could vary significantly with even minor route shifts.

The LRT route originally proposed by the MTC created two major concerns for the city. The first concern was the proposed use of Tasman Drive west from the end of the Santa Clara County Guadalupe Corridor line. The LRT route was then to cross the CA-237 Freeway and proceed to the vicinity of the Lockheed Company site. The industrial park sites associated with Lockheed were considered important destinations for LRT patronage. The Tasman route appeared to be the most direct way of extending the existing Guadalupe line, and offered a roadway width of about 60 ft in which a boulevard-type median could be constructed for the LRT line.

But the City of Sunnyvale was concerned that the roadway was barely wide enough for such a line, and that Tasman passed between three very large mobile home parks densely populated by elderly residents. The city was anxious to determine the exact space requirements and traffic impacts of the Tasman route, and to identify an alternative route to preclude a "take it or leave it" impasse with the local citizens.

The second major city concern involved the alignment south from Lockheed. The MTC proposed an alignment along Mary Avenue to the Southern Pacific (SP) Railroad right-of-way. Here would be located either an east or a west turn to follow the SP tracks to a terminal either at the Sunnyvale Town Center Caltrain commuter train station or to neighboring downtown Mountain View. The major advantage of the Mary route was its generous street width, within which LRT could easily be accommodated. The disadvantage of Mary Avenue was that it bisected a residential area and might bypass Sunnyvale Town Center on the way to Mountain View. A preliminary geometric analysis was needed to examine these problems.

The LRT route alternatives for Sunnyvale were developed in two stages, using design sketch techniques.

Step 1: Identify Alternatives

As the first step, city staff and consultants sought to identify new route alternatives, working with aerial photographs at a scale of 1 in.:200 ft. Scales of 1 in.:200 or 400 ft were preferred for initial sketching because they permitted an overview of the entire route, yet provided sufficient detail to identify all possible rights-of-way, such as local streets, contiguous parking lots, flood control channels, utility corridors, etc. Two large vellum overlays were used, each covering half of the route. On these overlays, a wide variety of possible LRT routes was sketched, using pencil lines to represent each trackway. At that stage of the analysis, all reasonable possibilities were sought, so that ultimately, the best one could be identified. Given the complex requirements of city planning goals, transit objectives, LRT operations requirements, environmental impact, and cost, the more obvious routes were not necessarily the best ones. Using single-line sketches, many alternatives were developed in a very short time. An example is shown in Figure 2.

In the Sunnyvale study, the design sketch method defined 12 new route alternative combinations in the Tasman-Lockheed area and 10 in the Lockheed-Town Center area. This work took about 1 week to accomplish. In the first area, one alternative, a route generally parallel to Tasman and consisting of Elko Street, a right-of-way along a flood control channel, and the CA-237 Freeway, was selected by the city for further review. The route was not as obvious as the Tasman alignment, had more curves and a longer freeway overpass, but was several hundred feet shorter than the Tasman route.

A similar sketch was used to define a preferred alternative to the Mary Avenue route in the Lockheed-Town Center segment. In that sketch, it was shown that the LRT line could follow a narrower local street, Pastoria Avenue, which serves a dense employment area of high-tech industrial parks. By passing through a number of existing parking lots, the Pastoria route could arrive more directly at the Sunnyvale Town Center.

Step 2: Define Impacts

In the second step, more detailed sketch plans were developed for the selected alternatives at a scale of 1 in.:100 ft. In locations where the geometry was difficult, the sketches proved that the LRT line could fit into the prescribed route, and made it possible to compare detailed impacts of the routes. Sketches developed over a 3-week period at the 100-ft-scale, prepared on a 3-by-10-ft sheet, were sufficient to illustrate fully 2 mi of line for two selected alternatives. All pertinent details could be shown, down to individual trees and parking places. It was possible at this early stage in the planning process to show the exact extent of trackway, individual traffic and turning lanes, prohibited turns, channelization and driveway geometry, curb cutbacks, station space requirements, potential landscape areas, and much more.

An important feature of the Elko route was the coordination of LRT geometrics with the redesign of the CA-237 Freeway interchange at Lawrence Expressway. To better accommodate LRT, the existing four-quadrant

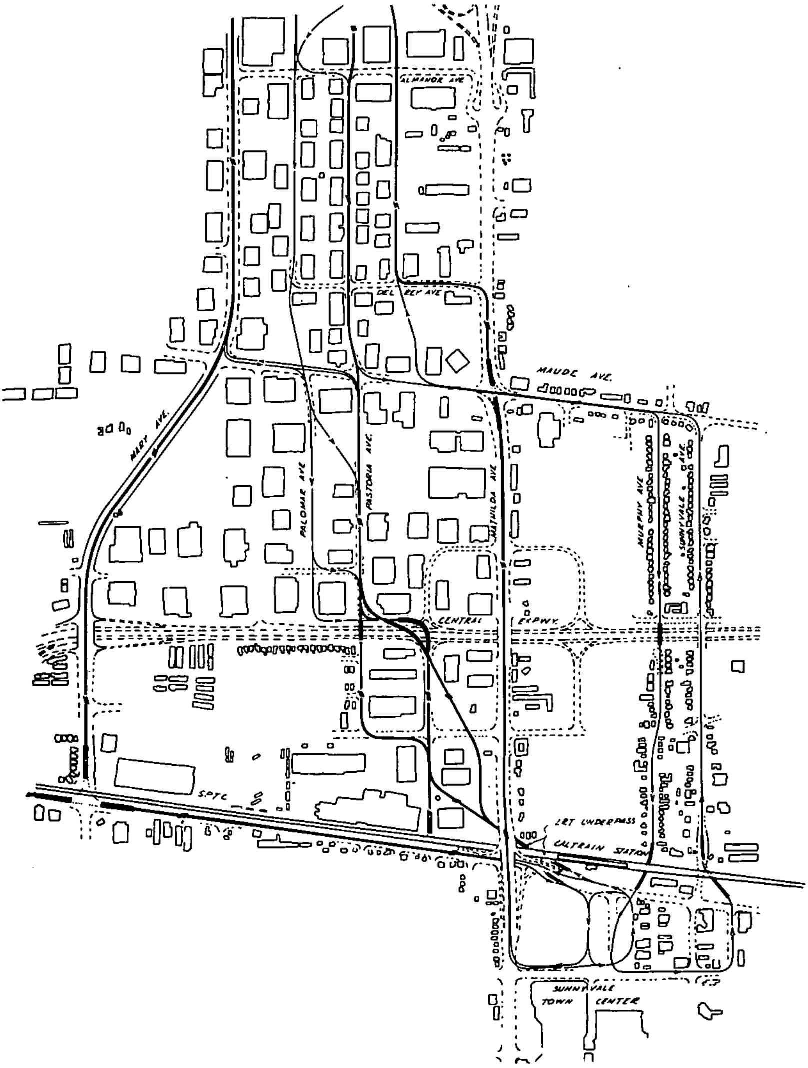


FIGURE 2 Single-line sketch illustrating numerous local route options for LRT from Lockheed area to Sunnyvale Town Center.

cloverleaf interchange was reconfigured into a more efficient partial cloverleaf (parclo), which demonstrated how improvements of road and rail systems could be coordinated and achieved simultaneously. The original sketch was later provided with a title block and colored for use in presentations to the city council and the public.

A large-scale design sketch was also prepared for the Pastoria route. This analysis identified the possibility of penetrating the Town Center by way of an underpass beneath the tracks and an existing overpass. Based on this possibility, the city intends to pursue a fully integrated plan for joint development of LRT and commercial expansion of the shopping center.

An example of the design sketch at 1 in.:100 ft is illustrated in Figure 3. It is compared with a more common format that uses tape on an aerial photograph and provides much less detail on the new facility.

DESIGN STUDY SKETCH FORMAT AND CONVENTIONS

For LRT, the important transition from planning to design occurs at the 1 in.:100 ft-scale sketch format, where, for the Sunnyvale study, the following project elements were physically defined for the first time:

- Right-of-way controls—Adjacent buildings are shown with heavy outlines. Other controls such as property lines, major tree lines, and structures are shown as necessary.
- Tracks—Each track (two rails) is shown as a single heavy line with an arrow indicating direction. Minimum distance between tracks is defined by the placement of the overhead system traction power poles between, or straddling, the tracks. Spirals are shown for curves, with track spacing on curves widened for carbody belly-in and superelevation.
- Stations—A rectangle is used to represent each station platform. Minimum length is defined by LRV length and maximum number of cars per train. At this stage, definition of center- or side-type platforms is made for the first time, based on availability of right-of-way, proximity of adjacent roadways, location of pedestrian crosswalks, and LRT operational requirements. In narrow rights-of-way, availability of width will, in many cases, define station locations and spacing.
- Roadways—For new road construction or modifications, each edge or curb of each traveled way is shown by a single line. Widths of roadways are based on local design standards. Existing curb lines are shown with lighter dashed lines. For a median LRT trackway, the left edge of pavement line also represents the center trackway boundary. Number of lanes is indicated by number of arrows, one per lane, in each segment of each roadway. Turning

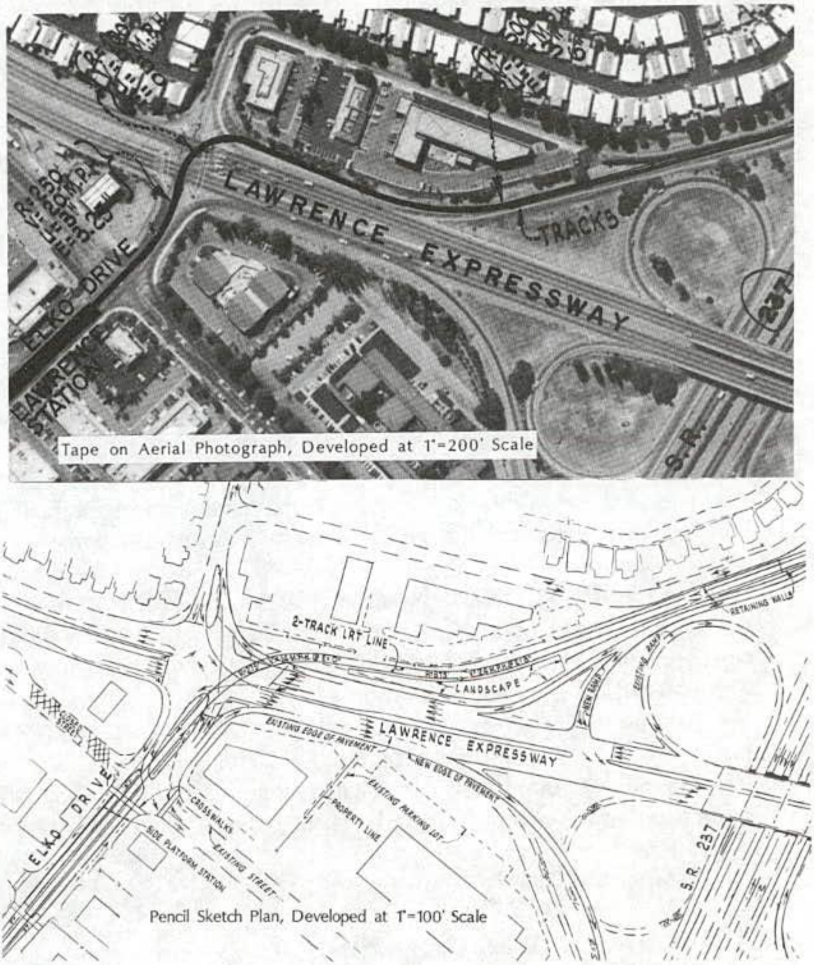


FIGURE 3 Comparison of geometric detail for preliminary planning on pencil sketch plan and tape-on-aerial photograph plan.

lanes are separated from through lanes by a fine line. Curb parking lanes are labeled.

- Channelization—All islands are shown, with adequate width and radius for turning vehicles. Arrows indicate permitted turns at intersections. All stop lines at intersections are shown.
- Crosswalks—Major crosswalks, such as those accessing station platforms, are shown. Crosswalk access is one of the factors defining feasible station locations.
- Traffic signal phasing—At each major intersection, a preliminary traffic signal phase chart can be shown, indicating the number of major phases. This may be required to define turning lane configuration.
- Grade separations—Parapet lines of bridge or underpass structures are shown as single or double lines. Extent of major retaining walls or pier locations, if significant, can also be shown. Width for emergency walkways should be provided. A profile sketch is needed to determine length of structures, fills, and retaining walls.
- Parking lots and driveways—If desired, the extent of any encroachment into adjacent existing parking lots can be clearly shown in the study sketch. Existing lot boundaries are shown with solid lines. Major driveways may require left turn access and should be shown, along with any relocated driveways.
- Landscaping—Potential new landscape areas can be outlined and labeled. Existing tree lines that are to be preserved constitute major geometric design controls.
- Dimensions—Critical or representative dimensions can be shown. Track curve radii should be shown, along with design speed based on assumed superelevation. (Track superelevation in paved roadway areas must be coordinated with roadway superelevation.)
- Profiles and cross-section—These can be sketched on the plan sheet or made separately. Profiles are important for defining grade separations.
- Options—If more than one local option is under consideration at the same location, an alternative can be sketched as an inset in a corner of the main plan.

ADDITIONAL USES OF DESIGN SKETCHING

In addition to their use in the preliminary analysis of alternative alignments and geometric design features, design sketch techniques can be applied readily to other aspects of LRT planning such as profiles, time-space graphs (train graphs) for operations planning, overhead system design, assistance in interdisciplinary coordination, identification of joint development opportunities, and as a basis for accurate early cost estimating.

Interdisciplinary Participation

Disciplines including trackwork engineering, LRT operations, traffic engineering, civil engineering and cost estimating, urban planning, structural engineering, landscape architecture, and traction power system design should be brought in early and integrated into the LRT alternatives analysis process. In particular, there is a compelling need to develop rail and roadway geometrics together to optimize use of the available space. This can best be accomplished in the early, flexible stages of project development.

An iterative process should be utilized to arrive at the best design for all purposes. This should include cooperative input from all appropriate disciplines early enough to affect the alternative selection process. Design sketching is an effective method of achieving interdisciplinary cooperation within the early planning stages.

Overhead Systems

The City of Sunnyvale has a very rigorous local policy encouraging landscaping of its thoroughfares. The preliminary geometric design prepared for Sunnyvale identified the need to preserve existing trees along the Tasman and Pastoria routes, and to use them to camouflage the trolley overhead. Side poles located in the tree lines were recommended. The more obvious alternative of center poles along Tasman was dismissed because a background of existing street trees favored the aesthetics of side poles.

Community concern frequently focuses on the visual impact of the overhead wires of a new LRT system. Examples of successful camouflage by buildings or trees along existing systems are frequently mentioned as a potential means of mitigation for a new system. To bring about such mitigations requires geometric design input at an early planning stage. Unsightly aspects of the overhead can be relocated, redesigned, hidden, or camouflaged. Major problem areas that need to be identified are special work at junctions and curves where numerous pull-offs, tension wires, and additional hardware are required. Trees can be used for either hiding wires or forming a softening background. The width required for a grove of major new trees needs to be considered early in geometric design, as does the coordination needed with the overhead layout. The ultimate result could be a true mitigation well worth the extra interdisciplinary effort, and the design sketch technique can effectively assist this effort.

Joint Development Opportunities

There are many examples of commercial and office joint development with rapid transit stations, but integration of development architecture with modern LRT has not been attempted often to date. Despite the few existing examples, LRT geometrics should be conducive to joint development. Quiet electric power and the physical flexibility of LRT can permit integration close to, and even within, the architecture of a major development. Accommodation of tramways within European historic plazas, through vintage archways, and even on top of multimodal terminals proves the physical feasibility of integrating LRT and architecture.

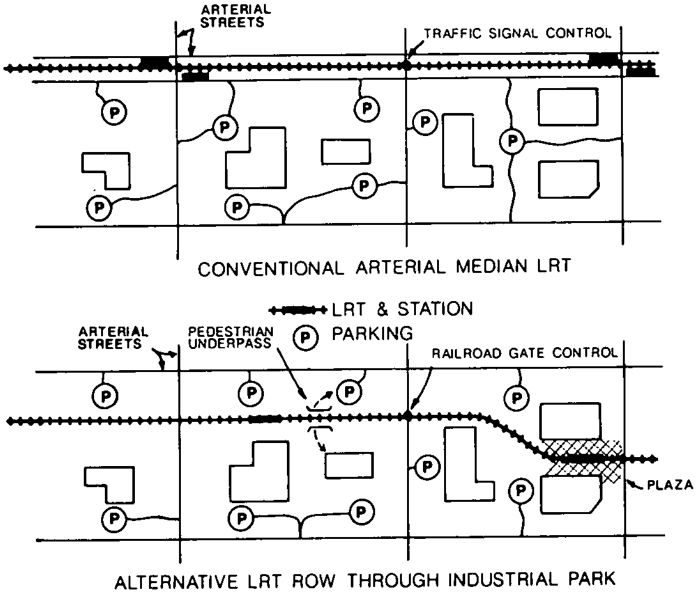
Geometric design options that bring the LRT line into available developable parcels, where more accessible and attractive passenger amenities can be encouraged, need to be sought out early. A local example of an earlier, innovative geometric solution that integrated a streetcar terminal into a building is the Transbay Terminal used by the San Francisco Municipal Railway. In San Diego, two joint development projects are being implemented that involve high-rise buildings constructed over LRT stations. Future joint development may lead to even more imaginative use of LRT geometric design flexibility.

Consideration should be given to locating LRT stations outside of street areas, closer to entrances of existing and new major buildings. For the Sunnyvale line, it would have been preferable to bring LRT to the door of one or more major Lockheed buildings. Unfortunately, in modern industrial parks buildings are usually surrounded with parking lots. Public rights-of-way are more easily obtainable for LRT use than private land. Thus, institutional disincentives may lead to LRT stations isolated in the street median, separated from the passenger destinations by streets and parking.

In contrast, as shown in Figure 4, LRT lines could be run behind the parking lots of the new industrial parks, directly linking the major building clusters. Each station then could become the center of a pedestrian-scale plaza, free of traffic conflicts. Creation of such a private right-of-way through existing industrial parks would involve more property acquisition and would be dependent on solving more challenging geometric problems. Advantages might include higher speeds due to separation of traffic conflicts, and avoiding utility relocations in city streets. Design sketching can help to bring out imaginative joint development options in the initial planning period.

Cost Estimating

The early availability of design sketches for cost estimating could be a vast advantage. More accurate estimates can be made in the early planning



CONVENTIONAL ARTERIAL MEDIAN LRT

ALTERNATIVE LRT ROW THROUGH INDUSTRIAL PARK

FIGURE 4 Routing concepts for LRT through an industrial park.

because the scope of the facility construction is available for quantity take-offs and measurements.

UMTA guidelines (*1*) suggest that preliminary cost estimates of rail systems may be based largely on cross-sections. This can be accurate for a heavy rail system, where most of the cost is confined to the guideway itself, and the guideway is mostly of uniform cross-section. For LRT in a city street, cost estimating by typical cross-section can be risky, because a significant percentage of the project cost may be due to geometric features outside the trackway. These may also be nonlinear, and vary in cross-section from segment to segment. Such features include street widening, intersection channelization, traffic signal installations, sidewalk and parking lot modifications, sound walls, landscaping, consolidation of driveways, and other such items where the new project must conform to existing conditions at the edges of construction. A detailed design sketch of geometrics that addresses these elements is a useful tool for more accurate early cost estimating.

HISTORY OF FORMALIZED SKETCH DESIGN

A formalized technique of freehand design sketching is not new. It was originally developed in the 1950s and 1960s for use in designing complex freeway interchanges and interchange systems. Formalized single-line sketch techniques for freeway alternatives were probably first developed by Jack E. Leisch, who later became the strongest and most effective advocate of the method. Leisch, who served in one period of his career as chief of design development of the Bureau of Public Roads, recalls that study sketches were first used in conjunction with an extensive study he prepared for an interchange complex in the Washington, D.C., area. This was accomplished in 1947–1948 at FHWA in Washington, D.C. It was during this study, as well as other projects involving interchange preliminary plans, that the study sketch technique for freeways evolved. The method was later formalized and officially reported for the first time in a 1948 paper (*2*).

The value of the procedure was well established in the ensuing years, and when the first "Blue Book" of the American Association of State Highway Officials (AASHO) (*3*) was released in 1954, it contained an appendix on "Intersection Design Procedure" that utilized much of the material from the 1948 publication. This served as a basis for developing and evaluating alternative plans and optimizing solutions for complex problems involving location, configuration, and traffic operation. In 1965, the design sketch technique was again published with minor changes in the second, revised version of the Blue Book (*3*).

During the 1960s Robert Conradt, working with Leisch, made a significant contribution in further formalizing the technique. His guidelines, as a chapter entitled "Notes on the Development of Single-Line Sketches," in a series of training course notebooks received wide circulation, and the studies he continued to perform enlarged upon the procedure. During the 1970s, Leisch, Conradt, and others continued to promote and refine these techniques. Sketching was also carried beyond the single-line format to include more detailed plans at larger scales. These larger scale formats are especially suited to LRT adaptations. The authors gratefully acknowledge Leisch's and Conradt's work on the concept of design sketching as well as a number of principles repeated in this paper.

The latest update by AASHTO in 1984, known as the "Green Book" (*4*), does not include the appendix of the previous AASHO publications. Perhaps implicit in the disappearance of the sketch technique from the AASHTO manual is the possibility that more glamorous computer-based design tools have overshadowed the simpler manual sketch techniques. Yet, even the most powerful computerized graphics now available have not obviated the practical need for initial conceptualizing using manual graphic methods. The sketch techniques may therefore be thought of as timeless in their import and value, and they remain available for use in LRT applications.

COMMENTS AND OBSERVATIONS

The Sunnyvale study brought some new insights on LRT planning to those who participated in the study, and it reconfirmed some other ideas that were held previously. The following observations relate to the study results and the study methods employed.

Alternatives Analysis Process

Geometric design of a transportation facility should begin in early planning. Planning for most fixed-guideway systems, including LRT, whether new starts or extensions, is now usually initiated in an UMTA-sponsored AA/DEIS process. By its nature, this process must deal with large-scale corridor alignment issues for numerous modes, of which LRT is usually only one. The flexibility of LRT can permit many local route options and geometric solutions, many of which may need to be addressed in the early scoping of alternatives.

The UMTA guidelines (*1*) recognize that supplementary analysis may be required in support of the scoping process to define which local alternatives are most attractive and need to be fully evaluated. The Sunnyvale study confirmed the need for this type of analysis and underlined the importance of defining more detailed geometrics in an early stage of project development.

The UMTA guidelines for the AA/DEIS process make a distinction between major alternatives that are to be included in the process, and minor variations that can be evaluated later in preliminary engineering. In a case where this distinction is not completely clear, as was true in Sunnyvale, a preliminary analysis of configuration and impacts can be useful. An early supplementary analysis can be helpful to a municipality in identifying environmental impacts that otherwise would not be addressed until later in the main environmental studies that follow alternative selection. Any new alternatives, if desired, can thus be identified during scoping as an informed decision. This also reduces the chances that major alternatives will need to be added later, possibly delaying the process.

Scope of Geometric Design

The question of what constitutes geometric design may require definition. System geometry includes the configuration and position of all visible aspects of the facility. The plan, profile, superelevation, and cross-section of the tracks and any adjacent roadways are elements of geometric design. Turnouts and special trackwork are geometric elements, as is station layout. Roadway elements of LRT geometry include traffic lane configuration, channelization, sidewalks, and crosswalks. Structures, such as bridges and subways, are special geometric elements. For LRT, the traction power overhead is also an important geometric design feature. Although the criteria of visibility may not include such features as underground utilities, ductwork, drainage, or structural systems, the implication of these may need to be taken into consideration in the geometric design.

Although geometric design is not limited to matters of appearance, it should address appearance, among other major issues. For example, public concern with the aesthetics of the overhead wire system is a recurring theme that requires special attention in LRT planning.

Geometric design is also directly related to transit operations. For example, the curvature and grade of the tracks can influence train speed. This affects travel time, scheduling, fleet size, and ultimately the quality of service and patronage. The geometric relationship of the LRT tracks and appurtenances to traffic lanes and pedestrian crossings is important in providing for operational safety. Potential conflicts need to be identified, and dealt with appropriately by such means as separation or controls.

Special Attributes of LRT

There are special attributes of light rail transit that have an influence on the planning procedures employed for this particular mode. LRT is extremely flexible in its geometry and therefore may have many route options. Light rail vehicles can negotiate much sharper curves and steeper grades than heavy rapid transit, and can utilize a wide variety of rights-of-way. LRT can fit into the cityscape in a multitude of patterns, not all of them immediately obvious. In contrast, heavy rapid transit routes may be limited to railroad rights-of-way, freeway medians, or costly subway. Light rail technology should allow, and even encourage, consideration of the richest possible variety of route applications. Identification, definition, and testing of all the many route options are required early enough in the planning process to permit selection of an optimum route. At the alternatives analysis stage it may be necessary to expand the number of alternatives as a prerequisite to later reducing them to ensure that the selected alternative is the best one available.

In some cases, the easiest LRT route—perhaps a railroad right-of-way or a wide street—is obvious from the start. The proposed route may, however, be circuitous or may not serve all the activity centers desired. In other cases, there may be no easily usable right-of-way, or the most obvious route may impose heavy operational disadvantages. Because of the flexibility of LRT, it is desirable in all these cases to carry out a preliminary geometric analysis early in the planning process to prove or disprove the functional viability of each route option, possibly including even the more obscure ones.

Formalized Design Sketching

No single prescribed format exists for working out preliminary geometric design of LRT or any other transportation facility. Although geometric criteria have been compiled into certain objective standards, the conceptualizing of geometrics is still a highly subjective process. The UMTA guidelines for the AA/DEIS process (*1*) refer to plan and profile drawings, and provide a sample of these. But the format does not emphasize the special needs of LRT, and may not illustrate the detail necessary or desirable for LRT segments in city streets. Although basic alignment can be shown as a simple line in plan and profile, the exact extent of street widening, layout of traffic lanes, new right-of-way, and the like require a more complex format. This is normally provided at the preliminary engineering stage, but it would be too late at that time to introduce major new alternatives. Preliminary geometric design needs to be developed through a rigorous study of alternatives. As previously described, the use of formalized design sketches was beneficial in quickly analyzing the large number of LRT route options through Sunnyvale.

The use of sketches may seem obvious, but formalized design sketching differs from the conventional diagrammatic sketches that most planners and engineers are accustomed to using:

Conventional Sketching

- Schematic—not to scale
- Usually conveys one or a few concepts
- No format—"off-the-cuff"
- Used to communicate to technical staff
- Little or no attention to graphic quality
- Usually small in size
- Short life—usually quickly discarded
- Redrawn by technician

Formal Design Sketching

- Accurate, to scale
- Integrates many ideas into one comprehensive analysis
- Carefully conceived graphic format and conventions
- May be used as a formal presentation medium to principals
- Graphic quality a major objective
- No size limitation—may be quite large
- Formal design product submittal
- Professional may produce final product

The development of small-scale sketches that subsequently graduate to larger scales of increasing complexity and detail can be one of the most important aspects of the planning and design process. In design sketch development the actual geometry of planning alternatives can be tested and matured into functional design. At this time, many of the features of the final design are first established and fixed. To be fully useful, design sketches must be developed with the fullest possible understanding and appreciation for the intent of project goals and objectives, as well as the practical limitations of the construction and operating environments. This is the only stage in which planning, design, and environmental mitigation can be given full and equal attention. The use of study sketch analysis can become the link between planning and design.

Sketches may be developed freehand with only limited use of drafting aids. Freehand pencil drawing allows ideas to be developed rapidly and permits fuller exploration of the design possibilities. It also develops a proper sense of perspective in executing the broader objectives of the plan by working with and visualizing larger areas of space. At the same time, the ability to deal expeditiously with long segments of alignment, no less rapidly than with fine details, is enhanced. The sketch method requires no costly equipment or special data base. The techniques can be easily learned or self-developed. The method is fast, and this has important relevance for the economy of the entire process in terms of both time and money.

Design sketches are not merely illustrations, but are simultaneously planning analyses and preliminary engineering designs. It should actually be possible to enlarge the sketches to the scale of the final design and to develop the final geometry from them directly with only moderate adjustments. Accuracy and attention to detail are therefore an important factor in the value of formal sketches. Unlike plans developed during later engineering, study sketches require no alignment calculation, all measurement being by graphic means. The fact that these have been developed largely freehand and may appear "sketchy" need not in the least detract from their accuracy if prepared with care.

The planner-engineer should endeavor to use study sketches to convey and test all appropriate ideas and all reasonable alternatives. Creativity and innovation are encouraged because of the speed of the method. Many geometric treatments can be shown, each identified as an option or variation. The process should stake out the extremes of the possible, in order—by contrast—to establish the practical optimum.

The method encourages the designer to tinker with, and constantly improve, the geometry. The freehand pencil line is easy to produce, to erase, and to redraw; the designer has little effort invested in each line, and should not hesitate to erase and modify it for improvement. Despite the detail that can be achieved, the design is free to evolve rather than being prematurely fixed.

Original sketches can become final presentation media. This can be easily accomplished by dressing up the sketch with labels and titles, and tracing major right-of-way controls from base maps. The finished print can also be colored using colored pencils. The possible objection to this product as "unfinished" or "sketchy" in comparison to such conventional media as sharp ink lines or tape on aerial map bases has little merit. The sketch should look tentative because the concept itself is still preliminary. The sketch medium encourages revision and participation in the evolving design. Popular ink and tape media have built-in disadvantages—they require the additional process of recopying the original design to appear more "finished," thereby cutting off the effort being devoted to conceptualizing. Ink and tape appear "sharp," but are not as specific and accurate as the pencil line. The freehand pencil sketch also encourages more direct participation by the professional-level engineer or planner.

The conventional use of aerial photographs as a base to enhance understanding of a preliminary plan may actually detract from the design by obscuring it with complex, irrelevant detail. Better to trace onto the plan only the limited number of most important right-of-way controls (e.g., adjacent buildings and streets) to emphasize the important, existing features that will be affected and their interrelationship to the LRT project. The use of large sheets is also to be encouraged to permit better perspective and understanding than a series of smaller discontinuous sheets.

The term "freehand" does not necessarily mean that drafting aids are not permissible. The exact technique employed can be altered to suit the individual practitioner. It is difficult to draw a long tangent line freehand, so most designers would prefer to use a straightedge even in "freehand" sketching. Naval architects' ships curves are excellent for track spirals. On the other hand, true freehand drawing is quicker, easier, and produces a better product for many curves, especially smaller radius curves and intersection channelization. The use of mechanical aids for these is actually a hindrance, and overdependence on instruments can result in a poor design.

Cost of Design Sketching

There could be some disadvantages in defining project geometry early in the planning process. Among the possible disadvantages are cost, requirements for staffing, and the danger of highlighting minor problems. The Sunnyvale experience indicates a cost for design sketch preparation of about $2,000 to $3,000 to detail a mile of LRT route alternative at the scale of 1 in.:100 ft. This is the cost of the engineering only, excluding data collection, meetings, and presentation time. If incorporated into the larger (and already costly) planning process, such additional cost should not be prohibitive, and could save later redesign costs. Alternatives that are identified earlier in the process are less costly to deal with than those that are discovered in later stages.

CONCLUSIONS

The LRT planning process should give ample attention to geometric design in the preliminary planning stage. An adequate number of different LRT alignments and geometric design alternatives should be developed and compared as a necessary preliminary step before a preferred route is selected.

The preliminary geometric design study should address rail and roadway features in a totally integrated fashion based on all of the appropriate interdisciplinary input. Formalized design sketching provides a valuable method for rapidly and accurately developing and testing LRT alternatives, and examining geometric design features. Design sketches are useful in detailing the specifics of the entire LRT route so that environmental impacts and costs can be clearly identified.

Design sketch methods have a long and successful history of use on transportation projects. The methods described can result in better design as well as better advance understanding of the potential impacts of a proposed LRT project.

REFERENCES

1. *Procedures and Technical Methods for Transit Project Planning* (review draft). U.S. Department of Transportation, UMTA, Washington, D.C., September 1986.
2. J. E. Leisch and D. W. Loutzenhieser. *Preliminary Design of a Major Interchange.* Public Roads Administration, Federal Works Agency, Washington, D.C., April 1948.
3. *A Policy on Geometric Design of Rural Highways.* AASHO, Washington, D.C., 1954 and 1965 editions.
4. *A Policy on Geometric Design of Highways and Streets.* AASHTO, Washington, D.C., 1984.