Diesel or Electric Power for Commuter Rail? It Depends . . .

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A study has been made for the North San Diego County Transit Development Board of the implementation of passenger rail service to an existing alignment that currently provides infrequent, low-speed, diesel-powered freight service over a 35.2-km (22-mi) right-of-way. At issue were the relative merits of the use of diesel-powered and electric-powered vehicles in providing superior service to a bus system currently in operation. Such performance analysis requires detailed definition of the alignment as well as the characteristics of potentially applicable vehicles. To provide the requisite data on the alignment, the physical characteristics were digitized, including curves, grades, tangent sections, and the location of station sites, in a form suitable for use as input to a computer simulation. A worldwide survey provided the requisite data on several diesel-powered and electric-powered passenger vehicles. Five potentially applicable vehicles (two diesel and three electric) were selected for the simulation process. Results of the simulation activity included speed and time versus distance profiles, energy utilization, and percentage of time at various throttle (power) settings. The simulation results showed that, on this specific alignment, there is little advantage to the use of electric-powered units over diesel-powered units. The reasons for this result were identified from the simulation data and are discussed in the body of this paper.

The North San Diego County Transit Development Board (NSDCTDB) was established by the California legislature in 1975 to plan, construct, and operate public transit systems in northern San Diego County. Its area of jurisdiction is 2 652 km^2 (1,020 mi^2) and includes the cities of Carlsbad, Del Mar, Encinitas, Escondido, Oceanside, Solano Beach, San Marcos, and Vista, as well as the Camp Pendleton Marine Base.

As part of its implementation plan, the Board has purchased the mainline right-of-way between Oceanside and San Diego and the branch line between Oceanside and Escondido, from the Atchison, Topeka and Santa Fe Railway Company. Passenger rail service on the San Diego mainline is currently being operated by Amtrak.

The NSDCTDB plans to implement commuter rail service between Oceanside and Escondido with an extension to the North County Fair Shopping Mall and an added loop to provide service to California State University, San Marcos (CSUSM). Use will be made of the existing Escondido Branch alignment. Currently, the line has a junction on its western end, with the Oceanside-San Diego mainline about 1.2 km (.75 mi) south of the Oceanside Transit Center Station, and terminates to the east in the vicinity of the Escondido Transit Center, a distance of slightly more than 35.2 km (22 mi).

Still to be resolved is the type of passenger vehicle best suited to the proposed operation. Self-propelled diesel-powered and electric-powered vehicles were considered. The electric vehicle offers better performance and lower noise and air pollution. However, it requires an overhead power distribution system not required by the diesel vehicles, and therefore, imposes more visual pollution and right-of-way (ROW) cost.

Electric-powered vehicles typically have higher power-to-weight ratios plus the ability to draw a large amount of additional power on a short-term basis, so they have superior performance characteristics when compared with diesel-powered vehicles. Although the advantage of electric-powered vehicles on straight and level track is clear, the performance on an actual alignment depends on the characteristics of that alignment, for example grades, curves, lengths of tangent track, and spacing of stations. Steep grades will adversely affect the diesel more than the electric vehicle. The superior acceleration of the electric will be of little advantage if curves are closely spaced, preventing the utilization of that acceleration because of curve speed limitations. Further, speed restrictions on an unsignaled alignment may further diminish the advantage of electric propulsion. On the other hand, the impact of the lesser acceleration capability and lower braking capability of the diesel may be exaggerated if there are many closely spaced stations so that the acceleration mode becomes a more predominant part of the operation. There are so many counteracting performance influences that performance comparison estimates on an alignment like that of the Escondido Branch can be competently made only through the use of a computer simulation incorporating not only the detail characteristics of the equipment but also the specific characteristics of the alignment.

The study described in this paper was initiated early in 1993 to provide insight and data to assist the Board in its decision-making process. This study incorporated the following process:

1. Define in detail the physical characteristics of the Escondido Branch alignment.
2. Survey the rail vehicle industry and obtain the characteristics of potentially applicable vehicles.
3. Select a small number of potentially most applicable vehicles, both diesel and electric.
4. Perform computer simulations using the combined alignment and vehicle characteristics as input to the RAILS simulation model.
5. Analyze and evaluate the simulator results and prepare findings.

This paper discusses each of the above steps in the process and presents a rationale for the somewhat unexpected results.

DESCRIPTION OF ALIGNMENTS

General Description

The planned alignment of the Oceanside-Escondido Line will include several new segments as follows:

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1. A new short section on the existing Oceanside-San Diego ROW between the Oceanside Transit Center Station and the Escondido Junction about 1.12 km (0.7 mi) south.

2. The existing alignment of the Escondido Branch from the Escondido Junction in a mainly easterly direction to the end of the line adjacent to the Escondido Transit Center and terminating in the vicinity of 4th Avenue between Redwood and Quince Streets in Escondido, a distance of about 34.1 km (21.3 mi).

3. A proposed extension from the current end-of-line, along an alignment in Pine Street, Center City Parkway, and Escondido Boulevard, to a terminal station in the parking lot of the North County Fair shopping center, a distance of about 6.4 km (4.0 mi).

4. A proposed CSUSM Loop segment, deviating from the Escondido Branch Line west of Valpredo Road, across SR78 and recrossing SR78 to rejoin the branch line just east of Woodland Parkway, a loop alignment length of about 2.72 km (1.7 mi).

Details of the alignment segments are shown on the Alignment Map, Figure 1.

Grades

Vertical profiles for all four segments are shown on Figure 2. (All grades in this report are stated as actual geometric grades and are not compensated for curvature. Ascending grades in the direction of increasing mileposts are designated as positive.)

The alignment transverses generally hilly country with little of the track bed on level ground. From an elevation of approximately 13.5 m (45 ft) at the Oceanside Transit Center Station site, the alignment descends to about 2.4 m (8 ft) at about milepost (MP) 0.6. It then rises steadily to an elevation of about 129 m (430 ft) east of Melrose Station site at about MP 7.8. From this peak, the alignment descends to an elevation of about 97.5 m (325 ft) near the Vista Transit Center Station site at about MP 9.3. It then rises to a new peak of about 156-m (520-ft) elevation at about MP 11.3. After descending again to an elevation of about 129 m (430 ft) at about MP 12.2, the alignment rises again, gradually, to its maximum elevation of about 207 m (690 ft) at the Nordahl Station site at MP 18.8. From this point, the elevation varies gradually to about 192 m (640 ft) at the end of the existing Escondido Branch at about MP 21.3. The proposed North County Fair Extension is relatively level to the Felicita Station at MP 22.5, then descends rapidly from an elevation of 198 m (660 ft) to an elevation of 114 m (380 ft) at the North County Fair station site at MP 25.3. This segment contains the steepest average and individual grades of the entire line. The average grade is −2.5 percent, and the maximum grade contained in the segment is −4 percent. Grades along the existing Escondido Branch and the planned North County Fair Extension vary from a few short segments of zero grade to many in the vicinity of 2 percent and one as high as 4 percent. The CSUSM Loop alignment

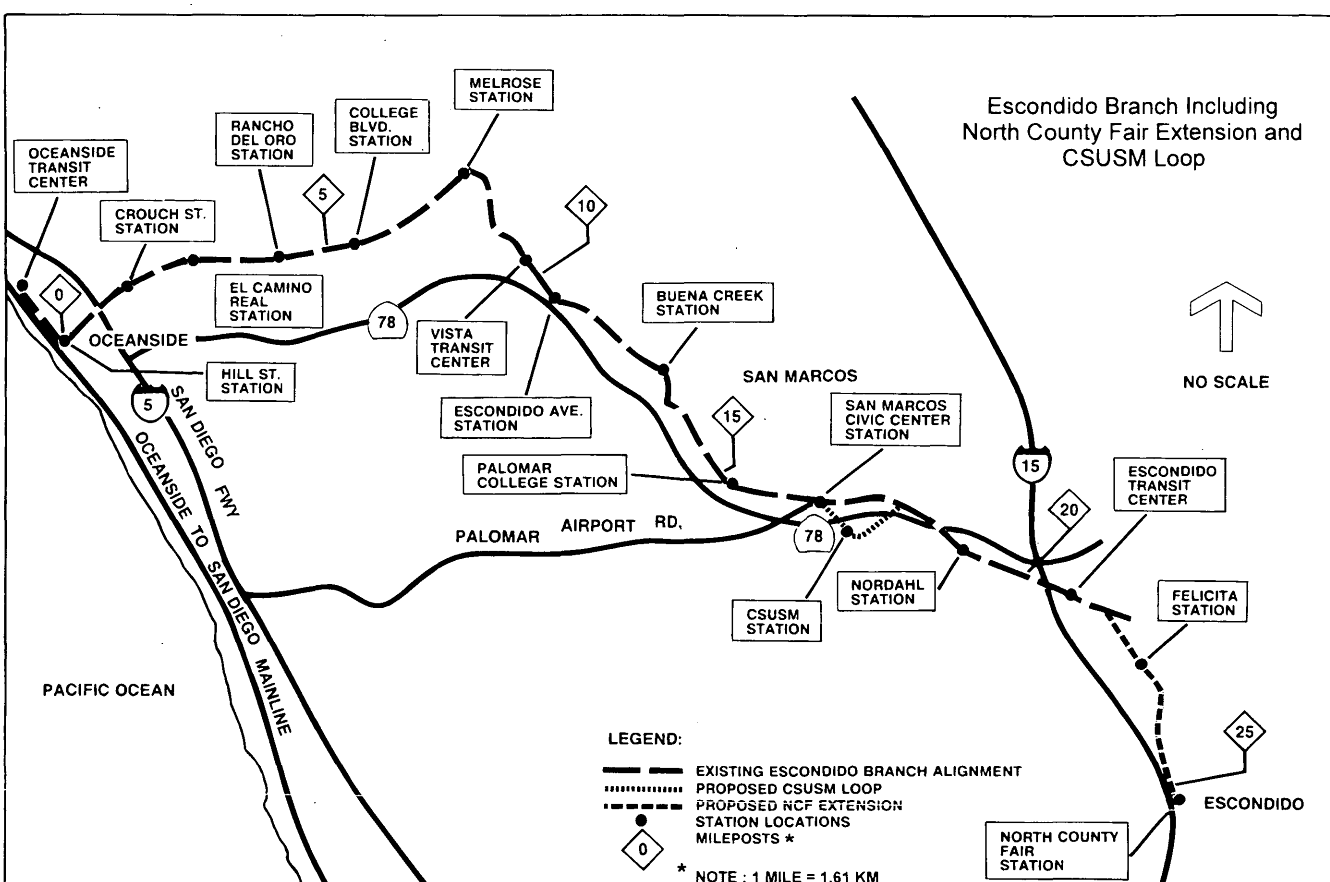

FIGURE 1 Alignment map.

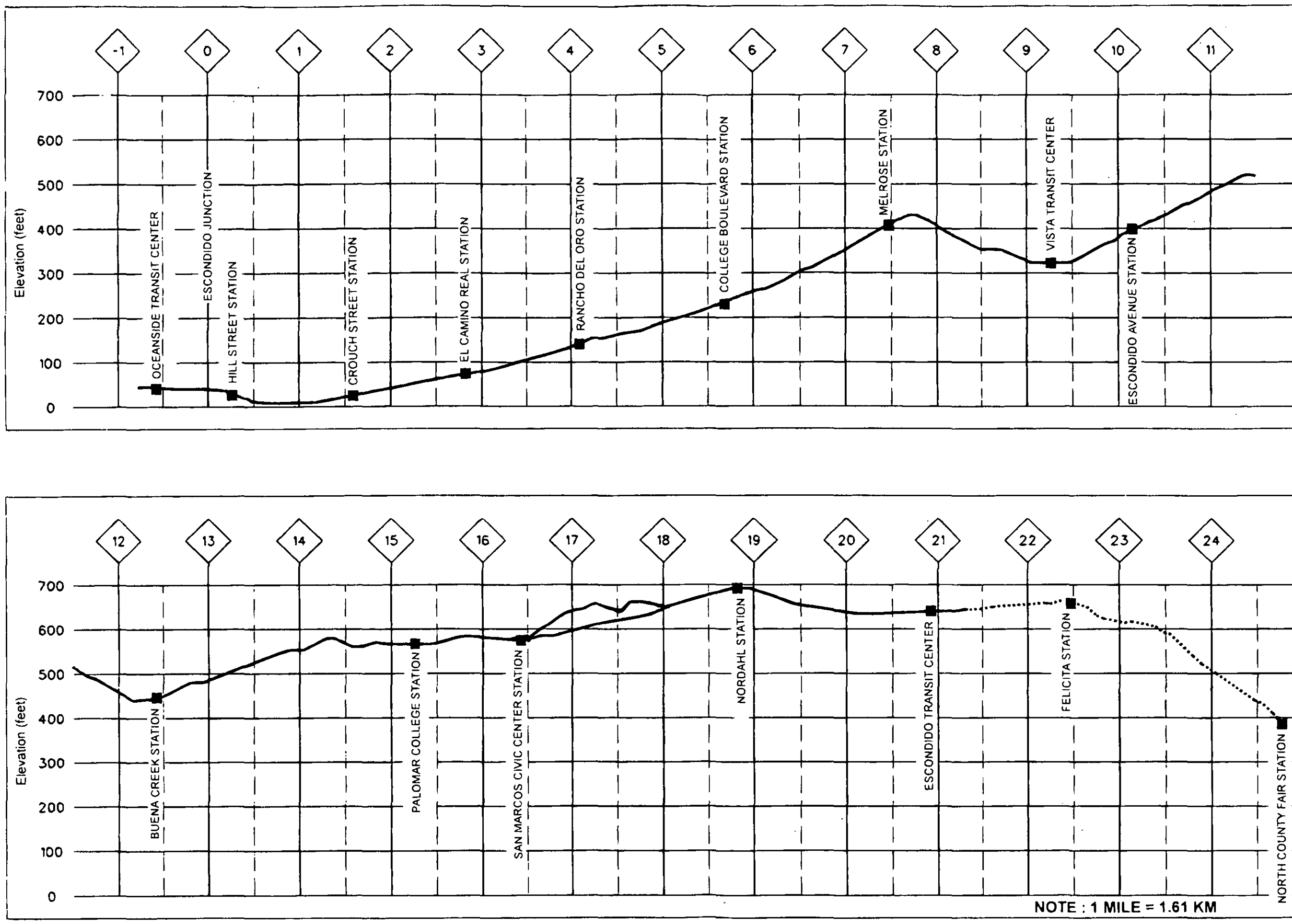

FIGURE 2 Alignment vertical profiles.

traverses similarly hilly country with grades reaching as high as 4.06 percent. Three new major bridges are included as well as a substantial amount of deep cutting into existing terrain. About 77 percent of the loop alignment is above existing grade.

Curves

The Escondido Branch alignment is characterized by many curves with few straight sections of any consequence between them. Over its approximately 33.6 km (21 mi) of length, there is one straight portion about 2.4 km (1.5 mi) long and two of about 1.2 km (0.75 mi) long. Others vary from about 0.8 km (.5 mi) in length to 0. There are 52 curves along the Escondido Branch varying from 1 degree to 10 degrees. There are several reverse curves with little or no intervening straight sections, limiting the use of superelevation. In a 1.6-km (1-mi) section of alignment, east of the Escondido Avenue Station site, there are eight curves of alternating direction of curvature with insignificant intervening straight sections.

The approximately 6.4 km (4 mi) of the planned North County Fair Extension contains 13 curves varying from about 3 degrees to about 27 degrees of curvature. It includes one straight section of about 2 km (1.25 mi). The 13 curves then occur in the remaining half of the alignment.

The approximately 1.12 km (0.7 mi) along the main line between the Oceanside Transit Center Station and Escondido Junction is all straight track. Two additional tracks and a passenger loading platform will be added in this segment of ROW to completely separate Escondido Branch operations from mainline operations. From the junction to the end-of-line of the Escondido Branch, 13 km (8.12 mi) of the 35.2-km (22-mi) length is taken up by curves. Thus, 38 percent of the branch line is occupied by curves. The planned North County Fair Extension has 1.7 km (1.06 mi) of curves in the 6.4-km (4-mi) length. This yields a combined curve length of 26 percent of the alignment length. The total line between Oceanside Transit Center Station and North County Fair Station, a distance of 41.6 km (26 mi), contains 14.7 km (9.18 mi) of curves occupying 37 percent of the length.

The CSUSM Loop alignment includes eight curves for an accumulated length of 1.3 km (0.8 mi) or a total of 47.3 percent of the length in curves. One major elevated curve changes the alignment direction approximately 90 degrees, from southward to eastward.

Stations

Including the new Oceanside Transit Center Station, the Oceanside-Escondido Line will have 14 stations, the North County Fair Extension, two stations, and the CSUSM Loop, one station, for a total of 17 stations system-wide at build-out. The alignment traverses a wide range of development characteristics, including dense urban residential and commercial areas, recreational, light residential and commercial, industrial, and agricultural. In other areas, the alignment is well sheltered from development of any kind.

Alignment Simulation Input

The detail physical characteristics of the alignment are an important input to the simulation process. For this purpose, the data from track charts, maps, and personal observation were assembled into tables of characteristics. Milepost designations for the beginning and end of each curve and change in grade, as well as the degree of curvature and the magnitude of the grade, were determined for all four alignment segments. Table 1 presents a sample of milepost positions of points-of-curvature (PC) and points-of-tangency (PT) as well as degree-of-curvature and direction for all curves. Positive values of curvature indicate curves to the right, and negative values, curves to the left. Also provided in Table 1 are the positions of stations.

MP 0 is located at Escondido Junction, so distances back along the mainline to the Oceanside Transit Center Station are designated by negative values. In addition, the distance along the CSUSM Loop between its junctions with the Escondido Branch is greater than the distance along the branch between these junctions (by about 0.64 km (0.4 mi)), so the MP along the loop have been identified by an *X*. The operating plan continues the freight operation on the branch alignment but is separated in time from the passenger trains, which will deviate from the branch and operate along the loop alignment. This has all been taken into account in developing the alignment data input to the computer simulation.

VEHICLE SURVEY AND DATA

Survey

A list of companies that manufacture vehicles potentially applicable to the planned Escondido Branch passenger rail service was compiled. Survey coverage was designed to include sources in the United States, Europe, and the Far East. The resulting list of potential sources contained 14 manufacturers. To assist in obtaining a complete and uniform set of responses, a data questionnaire was distributed, designed to provide general physical information on the equipment as well as the performance data necessary for input to the simulation studies.

Vehicle Data

Responses were received containing data on 14 vehicles, seven electric and seven diesel. The quantity and variety of responses is considered sufficient to allow selection of high state-of-the-art vehicles for the Escondido Branch study.

As a result of the survey, data was received on a range of equipment varying from small, light-weight, individual units with seating capacity for 45 passengers and seated weight of about 29,000 kg (64,000 lb) to multiple units with seating of about 180 passengers in a married pair weighing about 10 350 kg (230,000 lb) seated.

SELECTION FOR SIMULATION

A two-step selection process was used to reduce the number of vehicles to be subjected to the simulation process. In the first step, simpler, more obvious factors such as vehicle length and truck spacing were considered. These are important because the many curves and reverse-curves that exist on the Escondido Branch would introduce problems of clearance and passenger comfort with long vehicles and long truck spacing. Configurations with rigid lengths greater than about 2 250 cm (75 ft) were eliminated in the final stage of selection.

Seating capacity was normalized to a 2-2 configuration. Where an arrangement of 3-2 seating was submitted, the third row of seats was deleted from the vehicle capacity. For each seat so removed, the vehicle weight, empty, was reduced by 45 kg (100 lb). For vehicles where lounges and/or buffet areas were shown, it was assumed that seating would be provided in the same 2-2 pattern as for the remainder of the vehicle. The vehicle empty weight was not increased because seat weight was assumed offset by deleted buffet equipment weight. The increased number of passengers was included in vehicle loaded weight determinations.

TABLE 1 Track Characteristics

Limits	Curves		Grades %	Remarks
	Milepost*	Degrees		
PC	−0.78	−10°-0'	0.00	OCEANSIDE TRANSIT CENTER STATION BEGIN MAIN LINE
	−0.58			
	−0.38		−0.38	
	0.00		0.00	
PC	0.00	−6°-5'	0.00	BEGIN ESCONDIDO BRANCH
PT	0.02		−0.40	
PC	0.07	−5°-0'	−0.40	
PC	0.09	−10°-0'	−0.40	
PC	0.11	−3°-0'	−0.40	
PC	0.20	−8°-0'	−0.40	
	0.25		−0.40	HILL STREET STATION
PT	0.28		−1.60	
PC	0.30	−8°-0'	−1.60	
PT	0.35		−1.60	
	0.49	−8°-0'	−1.60	
	0.58		[illegible]	

* NOTE : 1 MILE = 1.61 KM

Vehicle capacity, per se, was not considered an important selection parameter at this stage of the analysis because system capacity can be adjusted to demand by selection of consist size and headway intervals. Vehicle general arrangement also was not considered a primary selection factor at this time. Factors such as seat arrangement, rest rooms, cab configuration, and boarding provisions can be modified to meet needs. An exception to the rule, however, is the requirement of a cab at both ends of the consist. For example, in the case of a power car with a cab at one end only, a consist of two power cars was required so that a cab would be available at either end. Where married pairs of motor and trailer cars were submitted, the trailer configuration with a cab at one end was selected for review for the same reason.

The inclusion of heating, ventilating, and air conditioning (HVAC) was mandatory. For diesel-powered vehicles, it was assumed that HVAC power would be provided from the main power source. The addition of HVAC was accompanied by a power reduction adjustment of 0.5 horsepower (hp) per seat for diesel units. No such adjustment was made for electric-powered units because HVAC power is normally not supplied from the traction power system.

For the second step of the selection process, the focus was on vehicle performance parameters. To aid selection, a Capacity-Performance Index, I, was developed as follows:

$$I = \left[\frac{N_s}{\mathrm{Aw}_0}\right]\left[\frac{\mathrm{hp}}{\mathrm{NA}}\right]$$

where

N_s = number of seats,
AW_o = empty weight,
hp = horsepower, and
NA = number of axles

I, then, is the product of the number of seats per pound of vehicle empty weight and the horsepower per vehicle axle. The value of I for each of the 14 vehicles is presented in Figure 3. These values, plus factors from the preliminary screening, were used to select for simulation the three electric- and two diesel-powered units as shown. These are *E-1*, *E-2*, and *E-3* and *D-3* and *D-4*.

SIMULATION INPUT

Assumptions

For the simulation software to provide realistic results, certain assumptions and limitations had to be identified consistent with the current and future status of the system. The resulting assumptions fall into three categories: ROW, traction power, and operations, as follows:

ROW Assumption

- The ROW consists of three segments: the first between the Oceanside Transit Center and the Escondido Junction, the second between the Escondido Junction and the Escondido Transit Center via the CSUSM Loop, and the third between the Escondido Transit Center and the North County Fair.
- Horizontal and vertical profiles are in accordance with the Description of Alignment (Section III).
- The existing line will be rehabilitated sufficiently to allow maximum speed limits for unsignaled territory.
- Curves will be superelevated to 3 in. where possible.
- No superelevation will be provided for curves closer than 150 m (500 ft).

Traction Power Assumptions

- Irrespective of power available, the application of power will be limited to not exceed acceptable levels of comfort (3 mphps).
- Electric motors have a short-term power rating of 1.7 times rated horsepower.
- Maximum tractive power (and braking) is limited to 18 percent weight on driving wheels.

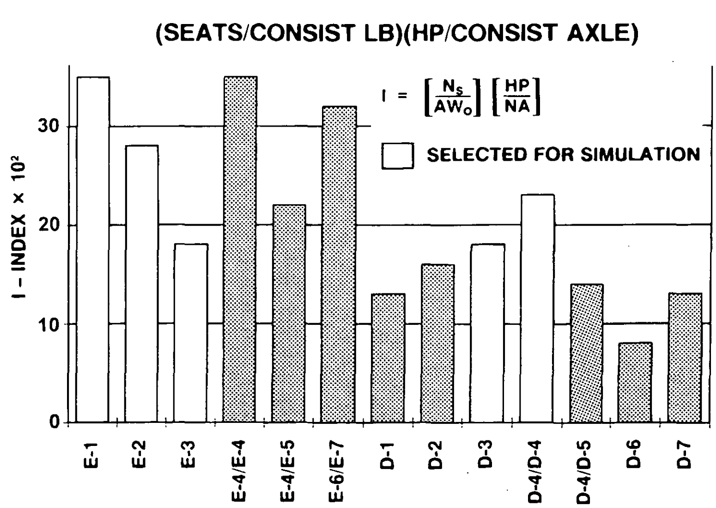

FIGURE 3 Capacity-performance index.

TABLE 2 Adjusted Consist Data

CON-SIST	NO. OF CARS IN CON-SIST	ADJ. NO. OF SEATS	ADJ. SEATED WEIGHT kg	NO. OF POWER AXLES	HORSEPOWER ADJ. TOTAL	PER kg WT. X10³	PER SEAT	PER POWER AXLE X10⁻¹
E-1 E-1	2	154	82,387	8	1,504	18.26	9.76	18.80
E-2	1	60	40,088	4	812	20.26	13.53	20.30
E-3	1	64	41,260	4	742	18.00	11.60	18.57
D-3	1	80	50,678	4	500	9.90	6.25	12.50
D-4 D-4	2	160	94,323	4	1,220	12.93	7.62	30.50

- Adhesion was reduced by 0.002 times speed to allow for dynamic unloading and to reflect typical tractive effort curves for both diesel and electric units.

Operating Assumptions

- The maximum speed on the line is 72 km/hr (45 mph).
- Speeds on curves are allowed to impose 3 in of unbalanced superelevation.
- Speed limits are not increased for short tangent sections.
- Dwell time at all stations is 30 sec.

Vehicle Characteristics

Applying all of the ground rules, requirements, assumptions, and limitations, consist characteristics for the five selected vehicles were determined. These characteristics, as displayed in Table 2, were used as input to the simulation. Note that two of the vehicles, *E-1* and *D-4*, were of single-cab configuration, requiring a two-vehicle consist. Tractive effort curves for the five vehicles are presented in Figure 4.

SIMULATION RESULTS

Speed Limits

A considerable amount of attention was given to careful definition of the physical characteristics of the alignment and to development of realistic operating ground rules. This information allowed the simulation software to establish realistic speed limits throughout. The resulting speed limit profile is presented in Figure 5. Thus, an absolute speed boundary was imposed that limited all acceleration and braking activities along the alignment. These parameters were further controlled by the location of the passenger stations.

Speed/Time Profiles

The speed and time variations for a typical run between Oceanside and North County Fair are shown on a computer printout in Figure 6. A comparison with Figure 5 shows that the software closely controlled the actual speeds to not exceed the imposed speed limits.

The heavy diagonal line is the profile of time versus distance. The short vertical segments on this profile are the station dwell times. For this run, the eastbound trip time was about 55 min.

Trip Time

One-way trip times calculated by the simulator for the five selected vehicles are presented on the left-hand side of Table 3. For the

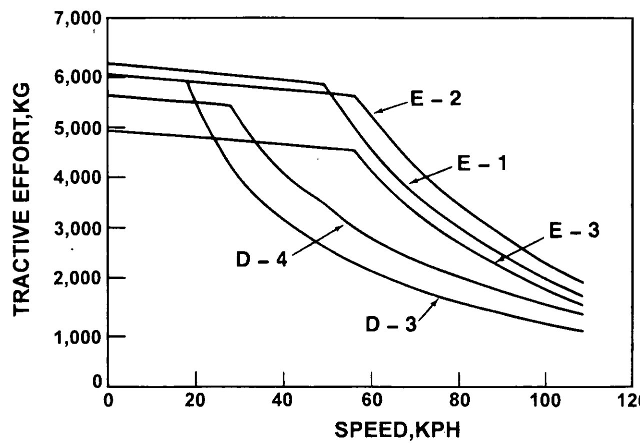

FIGURE 4 Tractive effort versus speed.

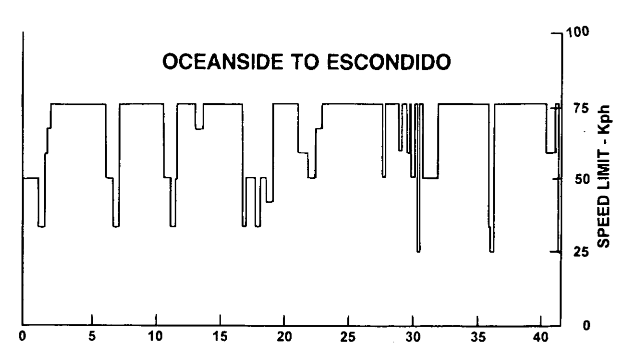

FIGURE 5 Speed limits.

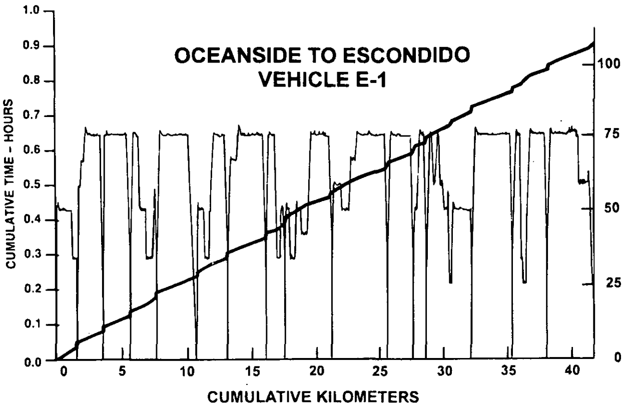

FIGURE 6 Time-speed-distance profiles.

established system speed limit of 45 mph, the times vary between 55 min and 57.6 min. The best time for an electric-powered vehicle is 54.8 min, and the best time for the fastest diesel-powered vehicle is 55.9 min, slower by about 1 min.

To test sensitivity of trip time to speed, runs were also made with a speed limit of 50 mph (Table 3). For the fastest vehicles, the trip times were reduced by 1 to 1.5 min. Note that this small improvement would require costly upgrading of the trackage and the addition of electrification and signaling systems.

Energy Consumption

The simulator also determined the quantities of energy consumed during a trip. These results are shown on the right-hand side of Table 3. Differences within a technology are minor. Of more significance is the energy cost per trip-seat. Such comparisons have been made and are presented in the following section.

Energy Cost Per Trip-Seat

The energy consumption data of Table 3 were converted to energy cost per trip-seat. For this purpose, costs of 10 cents per kilowatt-hour and 55 cents per gallon of diesel fuel were used. Seats-per-trip are based on the corrected seating values as provided in Table 2.

Results of the energy cost analysis are shown in Figure 7. Energy costs are presented for the electric-powered and diesel-powered vehicles as a function of the number of seats in the vehicle. Two trends are obvious. First, the diesel vehicles provide lower energy costs for a given vehicle seating capacity. Second, there is a significant trend of reduced energy-cost-per-trip-seat as the vehicle capacity increases. The difference in energy cost between the two technologies is reduced as vehicle capacity is increased. It appears that the difference would become negligible for very large vehicles of about 200 seats and above. For vehicles of about 75-seat capacity, the electrics provide a cost-per-trip-seat of about 41 cents compared with about 23 cents for the diesels. At a vehicle capacity of 150 seats, the electrics provide a cost of about 20 cents-per-trip-seat compared with about 13 cents for the diesels.

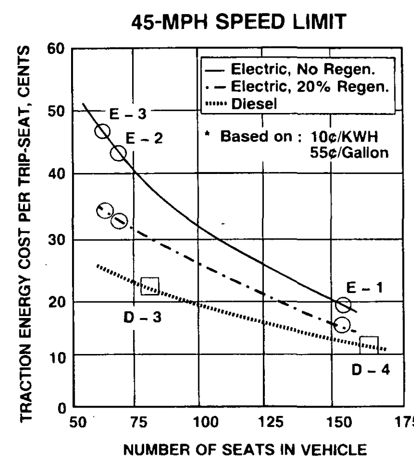

FIGURE 7 Trip-seat energy costs.

TABLE 3 Comparison of Energy Consumption

	ELAPSED TIME, MINUTES			ENERGY CONSUMPTION		
	75 KPH (45 MPH)	80 KPH (50 MPH)	DIFFERENCE	75 KPH (45 MPH)	80 KPH (50 MPH)	DIFFERENCE
E-1	55.06	53.32	-1.74	288.4 KWH	303.5 KWH	15.1 KWH
E-2	54.83	53.79	-1.04	288.3 KWH	308.5 KWH	20.2 KWH
E-3	56.07	54.62	-1.45	295.8 KWH	308.2 KWH	12.4 KWH
D-1	55.94	54.42	-1.52	139.6 L (36.9 GAL)	144.6 L (38.2 GAL)	4.9 L (1.3 GAL)
D-2	57.62	55.07	-2.55	127.2 L (33.6 GAL)	128.3 L (33.9 GAL)	1.1 L (0.3 GAL)

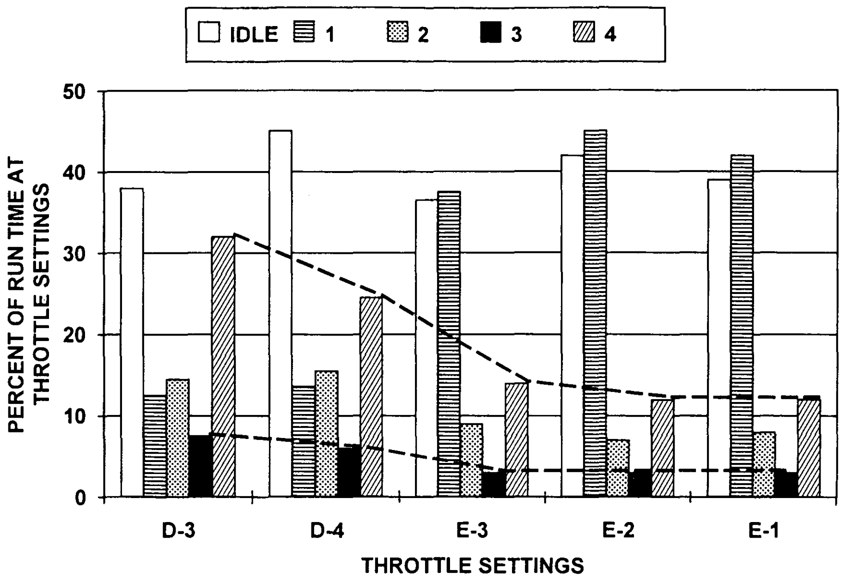

FIGURE 8 Traction power utilization.

To determine the potential impact on the energy cost comparison by regenerative braking, energy costs were determined assuming an optimistic value of 20 percent regeneration for the electric-powered vehicles. This regeneration capability was not sufficient to overcome the cost advantage of the diesel-powered technology. Further, it is unlikely that the commuter rail system under consideration would possess sufficient receptivity to provide any significant energy reduction from regeneration.

Traction Power Utilization

To better understand the trip time comparisons generated by the simulator, it was asked to provide percentages of trip time spent at various throttle settings. The diesel-power range was divided into idle plus four power settings. For comparison purposes, the continuous throttle setting spectrum of the electric-powered vehicles was divided into 20 settings in addition to the idle setting. Four groups of five of the throttle settings were established, each group of five being equivalent to one of the four diesel-powered settings above idle. In this manner, the relative times spend at each of the five throttle settings could be compared.

The power utilization simulation results are displayed in Figure 8, which contains groups of vertical bars for each of the selected vehicles. Each group of bars shows the percentage of trip time spent at each of the five throttle settings. It is immediately evident that both the electrics and the diesels are at the idle throttle position for more than 30 percent of the time.

For clarity, broken lines have been provided connecting the tops of the bars for the two highest throttle settings (three and four). The diesel-powered vehicles are at maximum setting for about 25 to 30 percent of the time, and the electric-powered vehicles required maximum throttle setting for only about 12 to 14 percent of the time. Similarly, for throttle setting three, the requirements were about 6 to 8 and 3 to 4 percent, respectively. It is obvious that the electric-powered vehicles possess far more power than is usable by the ROW limited performance of the Escondido Branch.

FINDINGS

This study has generated specific guidance for the implementation of passenger rail service on the Escondido Branch. It has also provided general guidance for planners engaged in the implementation process for any commuter rail service. These specific and general findings are as follows:

Specific Findings

There is no significant trip time advantage for the more highly powered electric vehicle for the following reasons:

- Because of alignment-specific performance limitations, advantage cannot be taken of the higher power of the electrics.
- Trip-seat fuel costs are lower for the diesel-powered vehicles.
- Because of the nature of the alignment, there is little to be gained by the expensive addition of electrification and signaling.
- There is potential for improved performance over that shown by more careful matching of the characteristics of the diesel units to the specific requirements of the Escondido Branch.

General Findings

- For other than alignments with ideal characteristics such as lengthy tangent sections, infrequent stations, signaling, and high-speed alignment geometrics, one cannot depend on the "conventional wisdom," and,
- For other than such ideal alignments, simulations should be used incorporating the detailed characteristics of both the vehicles and the alignment geometry.

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