Video sequences and digital material must be concise and to the point. Too much material confuses the employees. Some workers had trouble reading the material. Sentences shorter than those presented in the current design would facilitate understanding.

There appears to be a direct correlation between the interest of management and the enthusiasm of employees. Management needs to make a solid commitment to this type of training for it to be successful.

Publication of this paper sponsored by Committee on Railroad Operations Management.

Comparison of Freeway and Railroad Rights-of-Way for High-Speed Trains in the Texas Triangle

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ABSTRACT

Alternative rights-of-way for high-speed trains operating in the Texas Triangle, which connects Dallas-Fort Worth, Houston, and San Antonio, are described and compared in this paper. These alternatives include medians of Interstate highways and the former Rock Island right-of-way. It is concluded that cross-sectional geometry would allow construction of a high-speed rail line on the majority of the two types of rights-of-way. Two different microcomputer simulation programs were applied to the Texas Triangle to investigate different types of high-speed train technologies operating in Interstate highway medians and along the former Rock Island right-of-way. The simulation runs demonstrated that comfort and curvature limitations prevented full utilization of a 350-mph speed, and that lower speeds (150 to 200 mph) would appear more effective given the existing geometric constraints. In addition to operating characteristics, the Texas Railroad Company simulation provided estimates of energy requirements. The investigations demonstrated that 200-mph high-speed rail passenger service is technically feasible along existing rights-of-way in Texas.

Proposed routes for high-speed rail service generally use three types of right-of-way: (a) existing railroads, (b) existing highways, and (c) new alignments. Each provides a different set of benefits and problems.

Travel time, an important factor in attracting riders, is affected by the combination of physical route and performance characteristics of the trains. Human factors and mechanical limitations determine the maximum speeds at which a train can traverse curves and grades. Vertical and horizontal curves combine with train operation and performance characteristics to determine the time and distance necessary to accelerate and decelerate the train (1).

Use of computer simulations of train operation over proposed routes can yield information that is needed to make early policy decisions about appropriate technology and engineering designs, but multiple detailed mainframe computer simulations can be expensive. Microcomputers provide the ability to run low-cost, simplified simulations for sketch-planning purposes, which can help with comparisons of predicted performances of high-speed trains on various types of routes.

The studies described in this paper were directed toward assessing the physical practicality of implementing high-speed rail passenger service on existing highway and railroad rights-of-way in Texas. This paper does not include an investigation of market potential or a detailed analysis of the financial or legal feasibility of implementing and operating high-speed rail service in the Texas Triangle.

POSSIBLE HIGH-SPEED RAIL LOCATIONS IN TEXAS

One major U.S. corridor that has been considered for high-speed rail service is the 750-mile Texas Triangle, which connects Dallas-Fort Worth, San Antonio, and Houston (Figure 1). Investigations of potential routes for implementing high-speed rail passenger service in Texas have concentrated on using existing freeway and railroad rights-of-way. These routes were examined for physical and geometric

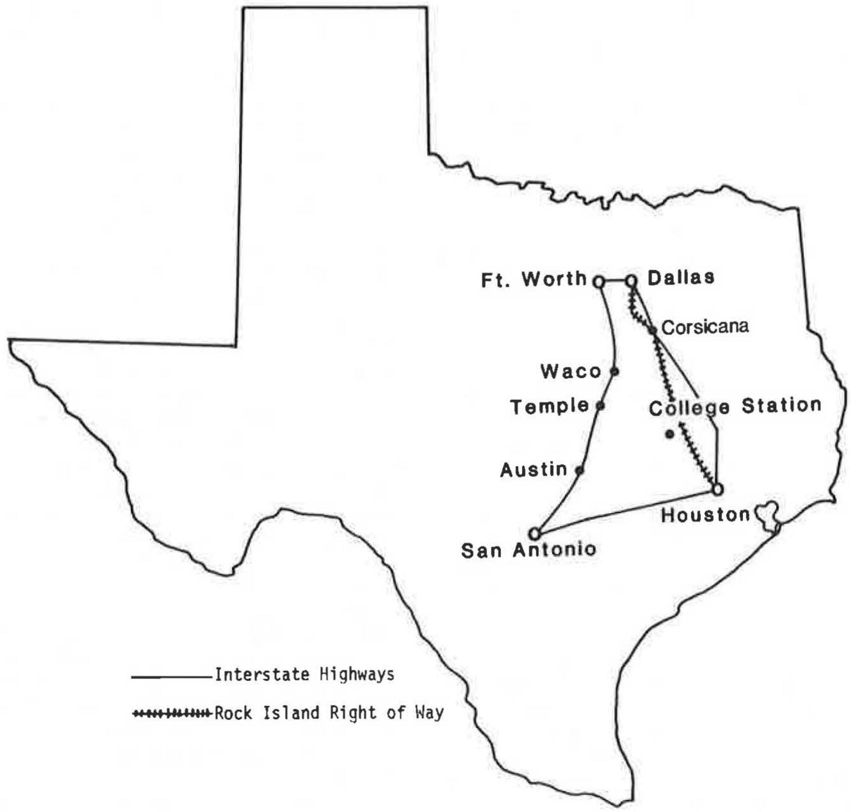

FIGURE 1 Map of the Texas Triangle.

features relevant to implementing high-speed rail passenger service within the right-of-way cross sections. A range of rail technologies, extending from operation at 120 mph to operation at 350 mph, were then superimposed on the longitudinal geometries of the right-of-way to determine their respective performance characteristics.

Interstate Highway Medians

A Texas Transportation Institute (TTI) research team surveyed 730 miles of the five Interstate highways in the Texas Triangle. Information recorded in the field included the following: (a) bridge structures, (b) overpasses, (c) vertical clearances, (d) major transmission lines, (e) milepost numbers, and (f) general observations. In addition, horizontal curve data were estimated from aerial photographs and county maps. Outside urban areas, the number of potential obstructions averages almost one per mile. The survey also considered weighted average surface width, roadbed width, and right-of-way width. To simplify the sketch-planning simulations, only horizontal curve data were used in the computer simulation program run by TTI.

Rural freeways in Texas are fairly straight and have relatively wide medians. Adequate median width exists along most of the route to allow construction of a high-speed rail system; such a system could be implemented at grade between the traveled lanes in a large portion of the Triangle. Medians 96 ft or wider would provide sufficient lateral clearance for double tracks while maintaining the 30-ft clear zone recommended by AASHTO. Considering safety along with noise and visual impacts, it may be desirable to construct barriers to shield the high-speed trains from adjacent traffic. At-grade construction, with appropriate protective devices, is feasible for two-way operation if median width is approximately 50 ft or more. Vertical clearances for an overhead power distribution system would be a problem at some locations.

Because of the variable design requirements associated with different high-speed rail systems and the geometric characteristics found at certain locations along the Interstate facilities (such as at major interchanges), it may be necessary or desirable to elevate portions of the guideway. Reasons to deviate from the at-grade construction could include topographic features (e.g., rivers), narrow medians, unsuitable horizontal or vertical curvatures, insufficient clearances, freeway structures, or some combination of these.

In urban areas, other problems can be expected. For example, in Houston the freeway medians have been dedicated to other uses, such as high-occupancy-vehicle lanes, and would not be available. Although more costly than an elevated guideway, a subway might be feasible; the exact configuration and dimensions of the tunnels would be determined by the high-speed rail technology selected.

Existing Burlington Northern-Rock Island Railroad Right-of-Way

The Burlington Northern-Chicago, Rock Island and Pacific Railroad Company (Rock Island Railroad) line is 240 miles long and runs between Houston and Dallas. Each party owns 50 percent of undivided interest in the southern 211 miles of the line from Houston to Waxahachie. The northern 29 miles of the line, from Waxahachie to Dallas, is owned by Missouri-Kansas-Texas Railroad Company and is operated by both Burlington Northern and Rock Island Railroad. Nine additional miles of the high-speed line are proposed, which would be on other rights-of-way.

The Texas Railroad Company has signed a contract to purchase Rock Island Railroad's interest in this line, which now has 96 bridges, 34 inactive railroad stations, and 122 turnouts and crosses 64 private roads, 224 state or county roads, and one major river (Trinity River in Dallas County). There are 123 curves with various radii; the total length is 33.40 miles, or 14 percent of the total mileage of the railroad; and the maximum grade is 1.00 percent. In general, the railroad right-of-way is 100 ft wide or more; this width is adequate for construction of three or four parallel tracks and drainage structures.

These rail-line characteristics are different from those of a highway right-of-way. Because the line already carries railroad traffic, it can be expected that the objections to noise and visual intrusion may be fewer than objections to noise and visual intrusion that would result from using a highway right-of-way. The problem of clearances will be less along an existing railroad right-of-way than along a highway right-of-way. On the other hand, Burlington Northern will insist on being kept whole, which will necessitate reconstruction of freight railroad tracks to one side and provision for access to (or compensation for) blocked industries. The railroad line as it now exists has many highway-railroad crossings at grade that must be upgraded to grade-separated crossings. Interstate highways bypass many towns, but railroads pass through their centers; either grade separation or, more likely, acquisition of new rights-of-way to bypass these towns will be necessary.

GEOMETRICS AND TRAVEL TIME

Most of the rights-of-way that were investigated have adequate cross-sectional geometry for construction of the high-speed rail lines. The feasibility of using existing rights-of-way for high-speed rail service also depends in part on longitudinal alignment. Freight railroads and freeways were designed for much lower speeds than those of high-speed rail systems; therefore, existing alignments constrain high-speed train operation. Vertical curves have an impact on project and energy costs but can be discounted in a preliminary analysis; grades of freeway rights-of-way are generally smooth and less than 5 percent, and railroad grades are much less than those of freeways. Horizontal alignment, however, can significantly affect grade separation, the need for extra right-of-way, and traffic disruption (2).

Restrictions on high speeds of trains at curves are largely the result of an effort to ensure passenger comfort rather than the inability of the train to negotiate curves at high speeds. One way to attain greater comfort when the train travels at high speeds through horizontal curves is to superelevate, or raise, the outside rail. For any given speed the degree of curvature and superelevation must be controlled to maintain lateral passenger acceleration and its rate of change (jerk) at a level that does not affect comfort. Although the Federal Railroad Administration (FRA) specifies a maximum of 3 in. of unbalanced superelevation (the extra superelevation that would be required to achieve equilibrium), recent studies (3,4) demonstrate the feasibility of using up to 4.5 in. of unbalanced superelevation in passenger trains that are equipped with stiffer suspension, without significantly affecting comfort. The French railroads have allowed for the use of a maximum of 6.3 in. of unbalanced superelevation in their Tres Grand Vitesse (TGV) train, even though in practice the unbalanced superelevation of the new Paris-Lyon line is less than 4 in. (5). At present, FRA regulations limit actual superelevation to 6 in., although in the past superelevations of 8 in. or more were used on North American railroads (6,7). Thus, train speeds on curves will be limited by unbalanced superelevation plus actual superelevation.

Another way of achieving balanced forces on the passengers is to tilt the passenger cars as done by the Swedish experimental train (8,9), the British Advanced Passenger Train (APT) (10-12), the Swiss (13), the Canadian Light Rapid Comfortable (LRC) (13), and the Italian State Railways (10,13). For example, a train could operate with 8 in. of actual superelevation plus 6 degrees of tilt (approximating 6 in. of additional superelevation) plus 4 in. of unbalance, which would provide a total of 18 in. of superelevation and thus higher curve speeds. It may be possible to add as much as 12 in. of track superelevation plus 6 degrees of tilt plus 6 in. of unbalance (which would give 24 in. of total superelevation) without inflicting undue discomfort on passengers who are either moving or stopped.

Magnetically levitated (maglev) trains could possibly achieve higher speeds. Although this emerging technology has not yet been placed in revenue service, maglev vehicles could be capable of greater superelevation angles; an actual equivalent superelevation of 20 in. could be feasible, but passenger mobility problems could arise if a maglev train were to stop on a curve with such tilt. Unbalance of 4 in. plus 20 equivalent in. of actual superelevation would provide a total superelevation of 24 in.

Unless it can be assumed that all curves have large enough radii that speed restrictions do not need to be imposed, curves along a selected right-of-way become important in simulation of train operations. By using the given geometric information, a computer program can determine controlling speeds on curves and thus develop an estimate of travel time.

SIMULATIONS

Two different deterministic simulation programs were used to "operate" high-speed trains in the Texas Triangle. One program, used by TTI and run on a Radio Shack Model III microcomputer, was designed to print a detailed velocity profile of train performance each 0.25 mile, but it did not consider grades or energy. To increase program running speed, the TTI program used a table lookup to determine at what point to begin deceleration. The second program, used by the Texas Railroad Transportation Company [now the Texas Railroad Company (TRC)], was run on an Apple IIe microcomputer. It did not print details of the velocity profile along the line, but used real-time calculations to consider overall energy requirements. Recall that the TTI program considered curves but did not consider grades; the TRC program considered grades and curves, but did not slow trains down to travel around curves. Yet when the TTI program was run with the Rock Island data and with assumptions of large radius curves, the travel times were essentially the same.

TTI simulations of both the Interstate highway rights-of-way and railroad rights-of-way assumed that the high-speed rail terminals were located at the interchanges of the Interstate highways. This is approximately the location of the Amtrak terminal in Houston, that is, just north of the downtown area. The Dallas terminal is located just east of the central business district.

Technologies Investigated

Three types of conventional steel-wheel-on-steel-rail technologies were simulated by traveling along the existing rights-of-way. Performance characteristics of these trains were estimated and used in the computer simulations.

The first set of rail parameters was estimated for a modern Amtrak train that consisted of 7 Amcar coaches pulled by an electric locomotive (Electric EMD AEM-7, 7,000 hp).

The second set of rail parameters was estimated to approximate the performance of a high-speed conventional electric train such as the German IC-E (Intercity Experimental) train of the French TGV with all axles powered, both with and without the ability to tilt up to 6 degrees on curves (approximating an additional superelevation of 6 in.).

The third set of operating parameters was estimated for a theoretical train. These theoretical capabilities have not, and may never be, attained in general operation with flanged steel wheels on steel rails, but they may represent a possible set of estimated operating parameters for maglev trains.

The Amtrak train was the lowest-performance option, and the theoretical train (or maglev) was used to represent the highest-performance rail option. The conventional diesel-powered passenger train operating on shared-freight railroad tracks was not included in the analysis.

A fourth set of ultra-maglev parameters, which resemble those of an amusement park ride or a jet airplane when taking off or landing, was also included to investigate their effects on travel time reduction. However, such operating parameters would require that the traveling public remain seated and belted throughout the run, which may not be acceptable in practice.

Except for the 120-mph maximum Amtrak speed, which was based on actual operation, maximum speeds of 200 and 350 mph were chosen to be representative of a general range of technologies. To facilitate comparisons, these three speeds were the only ones used on highway medians by the TTI program. Additional speeds were used on the Rock Island right-of-way. It should be noted that selection and use of these speeds in no way constitutes a recommendation or feasibility analysis.

Superelevations were matched to the maximum speeds allowed and the rail technology that was being examined. Except for the ultra-maglev system, maximum superelevation used was 24 in., which was composed of 12 in. of actual superelevation plus 6 degrees of vehicle tilt plus 6 in. of unbalanced superelevation. Although feasible, this amount of superelevation would make it difficult if not impossible to use highway medians because of the amount of spiral offset that would be required when entering and leaving curves. For the Amtrak technology, superelevation was assumed to be a total of 12 in., which is the sum of 4 in. of unbalanced superelevation plus 8 in. of actual superelevation for a standard gauge track of 4 ft 8-1/2 in. The 18-in. total superelevation assumed the same 8 in. of actual superelevation plus 4 in. of unbalanced superelevation, but with an additional 6-degree tilt capability of the train car bodies.

TTI Simulation of Highway Medians

A deterministic train performance simulation program was written in BASIC to generate train performance velocity profiles, travel time, and other data by reading route characteristics from a disk file.

Because the program operates on a small microcomputer and is quite slow, the program was kept as simple as possible to minimize run time. Table lookup was used to initiate deceleration, acceleration curves were approximated by straight-line segments, and performance was averaged over each 0.25 mile. Because analysis indicated that grades would have minimal effects on high-speed train operation over relatively flat terrain, such as that in the Texas Triangle, grades were not used (14). These limitations can allow for potential performance inaccuracies of plus or minus 0.25 mile and plus or minus a few minutes, with the possibility of a train entering a speed restriction at 1 or 2 mph over the speed restriction. These inaccuracies were considered more acceptable for the desired performance requirements than the alternative of increasing program complexity and run time.

It is important to note that train travel time is minimized by the TTI simulation program, and no attempt is made to save energy. If the train is not traveling at maximum speed (considering speed restrictions), and if it is not necessary to decelerate before an upcoming speed restriction or stop, then the train is accelerating at the maximum rate for its current speed range. This often leads to a constant acceleration-deceleration velocity profile that would waste energy; this is not the operating mode of commercial trains.

The TTI program was also used to investigate the effects of reducing curvature to allow higher operating speeds. For a high-speed train to travel at speeds faster than would be possible on freeway median curves, wider radius curves may be used; however, these curves may encroach on the main lanes. The highway alignment could then be modified or the railroad could be grade separated (15).

Reverse curves, such as those found on I-45 near Corsicana, Texas, may further complicate curve widening. The need for adequate spirals for smooth transitions between curves and tangents in the railroad alignments may increase the total lengths of two adjacent railroad curves to an amount such that the tracks may run away from the freeway median, and may even leave the Interstate right-of-way.

A train operating with a total of 18 in. of superelevation that is going around a 1.5-degree curve at or below 131 mph can follow the alignment of the freeway median curves shown in Figure 2.

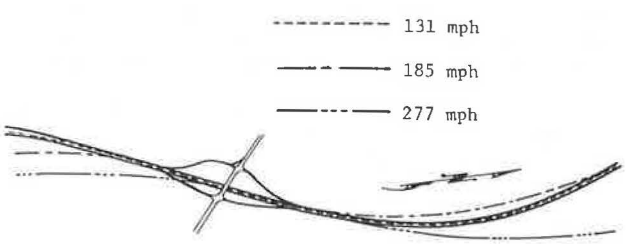

FIGURE 2 High-speed rail alignment through a reverse curve on I-45 near Corsicana, Texas.

Traveling at a speed of 185 mph requires wider curves than are available in the freeway median; this alignment requires shallow angle crossings over freeway main lanes and departure from the existing right-of-way at the center of each curve. Such alignment still begins and ends in the freeway median. For a train to travel at 227 mph the tracks must be constructed completely outside of the freeway median and right-of-way, along the curve.

TABLE 1 TTI Simulation Results of Trip Times of 9 Trains on Routes in Texas (min)

Type of Train	Speed (mph)	Superelevation (in.)	Route: Houston-Dallas I-45	Houston-Dallas Rock Island	Dallas-Ft. Worth	Ft. Worth-San Antonio	Houston-San Antonio
Amtrak	120	12	130.5	144.5	17.5	130.9	110.7
IC-E/TGV	200	12	94.0	121.8	13.5	96.7	78.5
IC-E/TGV/Tilt	200	18	86.5	108.6	12.3	87.0	72.6
Theoretical	200	18	82.4	102.5	11.6	85.6	69.4
Theoretical	350	18[a]	74.1	99.4	10.7	78.6	58.8
Theoretical	200	24	79.6	92.7	11.4	80.7	67.3
Theoretical	350	24	68.7	89.4	10.1	69.6	55.2
Ultra maglev	350	36	52.6	65.6	7.4	52.8	44.0

[a]Three special runs were made with this train; the trip times (min) are as follows: Ft. Worth to Austin, 55.6; Austin to San Antonio, 23.6; Houston to Dallas (Corsicana curves reduced), 72.0. Total trip time from Ft. Worth to San Antonio was 79.2 min plus station dwell time.

To test the effect of widening horizontal curves on travel time, a reduction of all curves to 0.5 degree over a 20-mile stretch of track near Corsicana was simulated. The results showed a total time savings of only 2.1 min for the complete Houston to Dallas simulation run. Because this was not considered significant, all other runs on Interstate highways were simulated with the tracks following the curves of the freeway medians. The slowing effects of curves are more pronounced on the railroad right-of-way, and would have a greater overall effect on schedule operation.

Results of TTI simulations of high-speed trains traveling in highway medians (15) are given in Table 1. These results suggest that traveling on the Amtrak train at a maximum speed of 120 mph would require less passenger travel time than would traveling by automobile, but would take significantly more passenger travel time that traveling by the available air mode. At the other extreme, the theoretical train (or maglev), which has a top speed of 350 mph, would reduce the amount of travel time to less than the amount of time required to travel by air. Yet it would save less than 18 min per run compared with the 200-mph German IC-E train or the French TGV train with all axles powered, but at higher construction costs and operation costs.

The ultra-maglev train saved almost 30 min on the Houston to Dallas run traveling at 200 mph compared with the theoretical train (or regular maglev), and more than 41 min compared with the nontilting high-speed train on the same run. However, it is questionable whether the seated and belted passengers would find the extreme accelerations and decelerations comfortable.

Within the limits of the TTI simulation program (deterministic assumptions, ±0.25 mile, and time errors of a few minutes), the following generalizations may be made:

1. Horizontal curvature on all routes prevents maintaining a constant speed of 350 mph. The majority of the time is spent accelerating and decelerating when the maximum speed is 350 mph.
2. Time savings between a 350-mph theoretical train (or maglev) at a 24-in. superelevation and a high-speed train with tilt at an 18-in. superelevation is less than 18 min, or 25 percent, on any route. The savings are most pronounced on the Houston to San Antonio route on which fewer curves are encountered along the route length.
3. Time savings between a 200-mph theoretical train at an 18-in. superelevation and a conventional high-speed train with tilt was 4 min or less per run.
4. A stop in Austin on the Fort Worth to San Antonio run added only 0.5 min (plus dwell time) to the time per run of the 350-mph train at 18-in. superelevation, because of the need to slow for curves in the Austin area.
5. Removing the 6-degree tilt of the high-speed train added 7.6 min to the Houston to Dallas run.
6. The Amtrak train was significantly slower for all runs, but it was faster than Amtrak passenger service scheduled in the past (e.g., 260 min on Burlington Northern from Houston to Dallas in 1963, and 335 min from Houston to Fort Worth on Amtrak in 1972).
7. The testing of curve easing over a single section of a route had only a minor effect on overall schedule performance. Reduction of all curves to 0.5 degree of tilt or less over a 20-mile stretch of track near Corsicana, south of Dallas on I-45, had only a 2.14-min effect on running time. (Note that this implication holds only for trains traveling in the highway median; widening of some, if not all, of the curvature on the Rock Island right-of-way would result in significantly greater time savings.)
8. With straight rights-of-way and a 350-mph top speed, travel time over the "perfect" 250-mile route from Houston to Dallas would be about 45 min per run.

TRC Simulation of the Rock Island Right-of-Way

High-speed train operation over the right-of-way alignment of the Rock Island Railroad line between Houston and Dallas was simulated by the Texas Railroad Company (TRC). The design and operating characteristics of the high-speed French TGV train were used as the basis for calculation because of the availability of data about this train.

Because it was found that it would be impossible to run trains at a constant speed of 150 mph or more over the line with its existing geometric characteristics, TRC's simulation assumed that curves would be modified by widening them to a minimum radius of 11,155 ft. This would cause no speed restrictions at 150 mph if 6 in. of actual superelevation plus 6 in. of unbalanced superelevation were used.

The trade-off between saving time and saving energy was investigated. Basic energy consumption depends on the configuration (geometry) of the right-of-way and the design of the rolling stock. The French TGV train (or a similar German or Japanese train) represents one of the most advanced technologies in the field and is energy efficient. The French railway industry has investigated intensively the configurations of the propulsion system and the aerodynamic shape of the rolling stock (16). On a per-passenger basis, a TGV train traveling at 160 mph consumes less energy than a conventional train traveling at 100 mph.

An initial microcomputer analysis was conducted by TRC to determine expected performance of the high-speed train in the Houston-Dallas intercity corridor. Technical data on the French TGV were used when available to calculate tractive effort and train motion resistance (16-18). The TRC simulation assumptions included:

1. Standard M-8-M train set of 418 tons and 385 seats;
2. No speed restrictions;
3. Specific acceleration of 2 km/hr/sec or 1.25 mph/sec;
4. Specific deceleration of 2.8 km/hr/sec or 1.75 mph/sec;
5. Propulsion system efficiency of 0.80;
6. Catenary efficiency of 0.85;
7. Electrical substation efficiency of 0.85;
8. Power transport line efficiency of 0.85;
9. Power plant efficiency of 0.30;
10. Specific cost of $0.05/kWh, and
11. Auxiliary devices power of 3.5 percent of propulsion system.

The TRC simulation program combined the mathematical models of energy consumption, train resistance, and schedule time. Power on the train must overcome resistance to motion, accelerate the train, decelerate the train, and power auxiliary devices.

Resistance to train motion arises from mechanical resistance due to the rolling of the wheel on the rail and internal friction and oscillation and air resistance, which depends on speed and the surface of the maximum cross section and on the effects of friction along the sides of the train.

By using the tractive effort developed by the propulsion system, which depends on speed and trainset resistance, the TRC computer simulation program integrated the train motion equation. Given train velocity and train position at the beginning of the time interval, the program simulated the next train position at the end of that interval. The program generated the step-by-step speed-time-position trajectory of the train and the power consumed.

Output of the TRC program gives schedule performance, energy consumption, peak power demand, specific energy consumption, and cost of energy for 44 train sets per day between Houston and Dallas. General results include:

1. Running time is 101 min between Houston and Dallas, there are no intermediate stops, and the average speed is 146 mph (over a slightly shorter route of 246.5 miles with widened curves that do not require speed restrictions).
2. Energy use for a single standard M-8-M train set (motor unit, 8 cars, motor unit) over the route was 7,031 kWh at the substation, or 0.0921 kWh per passenger mile based on 80 percent occupancy of the 385-seat train.
3. Energy-use increase at higher train speeds is approximately proportional to speed increase raised to the 1.8 power.

According to French experience, the most economic speed appears to be in the range of 140 to 165 mph. The simulation runs support this; how longer travel times affect the attraction of passengers to rail travel was not simulated, however.

TTI Simulations of the Rock Island Right-of-Way

For comparison, the TTI simulation program was run without curve restrictions at a speed of 150 mph, which gave essentially a trip time of 101.5 min between Houston and Dallas; this compares to the TRC simulation program time of 101 min. In addition, the simulation runs by high-speed trains were performed over the existing curvature (see Table 1). The theoretical train at 24 in. of superelevation was able to operate at the maximum speed of 350 mph for only 1.5 miles during the 249-mile trip (less than 1 percent) because of curves. Thus, the TRC simulation assumption that curve smoothing is necessary to increase train speed was validated.

IMPLICATIONS OF THE SIMULATIONS

One significant implication of the simulation runs is the suggestion that a maximum speed of 350 mph along highway medians or existing railroad routes may not be cost-effective. Maximum time savings would be only 18 min, whereas the increase in construction, vehicle, and operating costs would be disproportionately high. Assuming a riding population of 6,000 passengers per day, with the value of their time at $7.00 per hour, the 18-min time savings would result in a value savings of $3,276,000 per year. This savings would cover the interest on $32,276,000 of capital at 10 percent, if all additional energy costs are ignored, which is much less than the capital investment required to smooth curves over the entire route. Analysis of the velocity profiles that were generated show that the 350-mph train would not be able to maintain maximum speed over the majority of the routes.

Houston to Dallas trip times along the I-45 right-of-way plotted as a function of maximum train speed can be seen in Figure 3. Increases in speeds above approximately 200 mph do not result in significant travel time reductions; the curve in the figure shows that minimum trip time for an existing route is approached at 350 mph. The spread of points at 200 mph and 350 mph is due to the points representing different technologies and superelevations. It is important to note that this curve is for a single existing alignment, and the curve should not be directly applied to any other route. Nevertheless, assuming that the TRC energy-use calculations for the Rock Island right-of-way would be similar for the I-45 right-of-way, it can be seen that an increase in maximum speed to 350 mph would result in a significant increase in energy consumption without a concurrent reduction in trip time. Because of the amount and degree of curvature on this route, the 350-mph trains were unable to operate at maximum speed over most of the route.

The 200-mph German IC-E train or French TGV train with all axles powered, on the other hand, were able

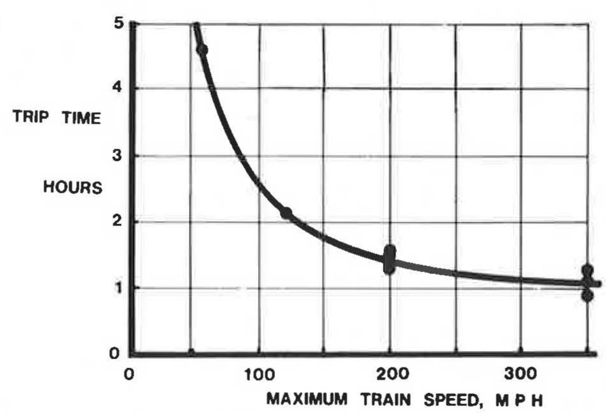

FIGURE 3 Houston-Dallas trip time on I-45 versus maximum speed.

to operate at maximum speed for a significant portion of time. This type of train took only 94 min to go from Houston to Dallas along the highway median at 200 mph, operating with no tilt, 101 min over the Rock Island right-of-way at 150 mph with no curve speed restrictions, and 108.6 min operating with tilt and a top speed of 200 mph over the existing Rock Island right-of-way. If airport access-boarding time of 30 plus 20 min is added to flight time, downtown-to-downtown train travel time is essentially the same as air travel time between these two cities. The 86.5-min travel time that is possible with a German IC-E train or a French TGV train operating with tilt is quicker than the total central-business-district to central-business-district air travel time. Assuming that train fares would be lower than air fares, the existing TGV-type of technology (possibly with 6 degrees of tilt added) should be adequate to cause a significant diversion of passengers from other modes to the train.

The 200-mph speed used with the high-speed trains was arbitrarily chosen; although 200 mph appears to be close to the most effective speed needed to attract significant numbers of airplane passengers, no sensitivity analysis was made. Thus, 200 mph must not be considered a magic number; it was merely a convenient number for this preliminary analysis, a number the use of which gave good results. The TRC simulations suggested that 150 mph might be more economical in energy usage, but it may range downward or upward by a considerable amount. The significantly longer travel times required by the Amtrak train could result in less diversion of intercity traffic, which would make this option less effective than the higher speed 200-mph trains.

Use of microcomputers to simulate the operation of high-speed trains on the Texas Triangle by using BASIC programs was a success. Although the results were not as sophisticated or accurate as those that might be obtained from a mainframe simulation, the results were adequate for defining the relative effectiveness of different types of technologies over an available route, by estimating travel times and other parameters with a minimum of input requirements and an acceptable degree of accuracy.

SUMMARY

The studies and simulations suggested that a conventional high-speed train similar to the West German IC-E or French TGV (or maglev), operating at a maximum speed of 150 to 200 mph, would be capable of operating on the former Rock Island railroad route, or over existing highway rights-of-way, at scheduled speeds and with time savings capable of attracting passengers from other travel modes, using a reasonable level of energy consumption. The TTI simulation detailed speed bottlenecks, and the TRC program calculated energy requirements.

These findings, which were an outcome of sketch planning, were derived by using microcomputers. The simulations proved valuable in establishing the directions of further studies, and in defining the engineering problems and technology that could be pursued.

ACKNOWLEDGMENTS

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