of traffic distribution between two ways on speed is twice that of volume. (d) The developed models can yield site-specific speed estimates with margins of error of less than 1 percent. (e) The model developed from one site is capable of predicting the speed at other sites with similar design standards. The results of this study provide some general guidelines for road engineers and managers to use in selecting cost-effective road design standards and developing cost-effective road management programs for one-lane roads with turnouts.


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REFERENCES


1. Highway Capacity Manual 1965. HRB Special Report 87, HRB, National Research Council, Washington, D.C., 1966, 397 pp.
2. J.J. Byrne, R.J. Nelson, and P.H. Googins. Logging Road Handbook: The Effect of Road Design on Hauling Costs. Agriculture Handbook 183. Forest Service, U.S. Department of Agriculture, 1960.
3. Forest Service Handbook 7709. U.S. Department of Agriculture, Chapter 11, Dec. 1981.
4. F.-L. Ou, A.J. Hessel, L.W. Collett, and D.R. Nordengren. Effect of Road Design on Timber Hauling Speed in the United States. In Transportation Research Record 898, TRB, National Research Council, Washington, D.C. 1983, pp. 61-65.
5. Interim Materials on Highway Capacity. Transportation Research Circular 212, TRB, National Research Council, Washington, D.C., Jan. 1980, 276 pp.
6. C.L. Dudek and S.H. Richards. Traffic Capacity Through Urban Freeway Work Zones in Texas. In Transportation Research Record 869, TRB, National Research Council, Washington, D.C., 1982, pp. 14-18.
7. R.E. Dudash and A.G.R. Bullen. Single Lane Capacity of an Urban Freeway During Reconstruction. In Transportation Research Record 905, TRB, National Research Council, Washington, D.C., 1983, pp. 115-117.


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*Abridgment*

# Computer Simulation To Compare Freeway Improvements


**ROBERT W. STOKES and JOHN M. MOUNCE**



ABSTRACT

Use of a simulation program, FREQ6PE, to compare proposed improvements for the Southwest Freeway (US-59) in Houston, Texas, is described. The simulation model was calibrated using actual field data and was then used to identify the best of a number of proposed geometric improvements. The proposed improvements were evaluated by comparing key simulated measures of effectiveness for the proposed systems with comparable measures for the base (do-nothing) system. Based on the experience gained in using the program, it is concluded that the program can be an effective and economical tool for studying the dynamic response of a freeway to a variety of input specifications.


The Southwest Freeway (US-59) bisects one of the fastest growing corridors in the Houston region. Traffic demands on the freeway outside of I-610 (see Figure 1) have increased 45 percent over the past 5 years to an average daily volume of about 194,000 vehicles. Depressed levels of service often extend from 6:00 to 9:00 a.m. and from 4:00 to 7:00 p.m., with trip times frequently tripling from off-peak to peak periods (1).

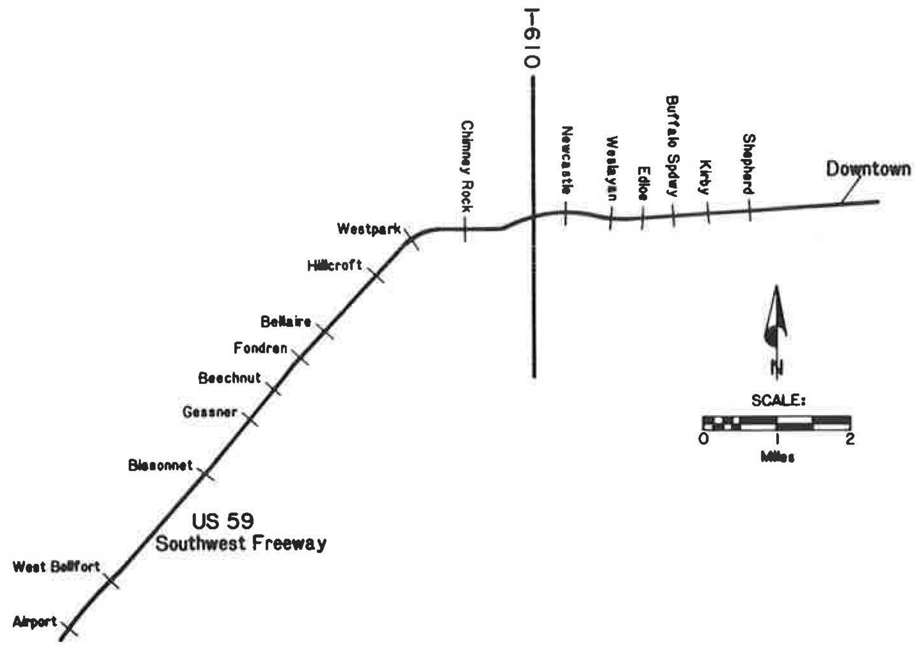


FIGURE 1 Southwest Freeway study corridor.

As a consequence of the continuing growth within the corridor and the corresponding declines in freeway levels of service, a number of geometric improvements have been proposed for the corridor. The FREQ6PE simulation program (2) developed at the University of California at Berkeley was used to evaluate the proposed geometric designs. A summary of the improvements evaluated is given in Table 1.

The objective of the computer simulations was to quantitatively assess the proposed design configurations and identify the configuration or configurations that best satisfied the objective of maximizing person throughput on the facility. The basis of comparison for the improvements was the 1995 do-nothing alternative.

TABLE 1 Improvements Evaluated

| Improvement | Description |
|---|---|
| Do Nothing | No Improvement. |
| Add One Lane | Add one freeway lane over the entire length of the study corridor. |
| Add Two Lanes | Add two freeway lanes over the entire length of the study corridor. |
| Add Shoulder Lane | Add a shoulder lane from Westpark Entrance to I-610 Exit. |
| Stack Ramps | Stack (elevate) ramps at: a) Buffalo Speedway Entrance/Kirby Exit; and b) Kirby Entrance/Greenbriar Exit. |

## APPLICATION

### Model Calibration

Freeway main-lane demands were input to the FREQ6 model in the form of mode-specific origin-destination (O-D) tables by 15-min time segments for the morning peak period (6:00-9:30 a.m.). Additional input included pertinent geometric data and speed-flow curves. The calibration process involved graphically comparing measured travel times and observed queue length with model output. The capacities (service volumes) of critical (bottleneck) sections were adjusted until the model output approximated observed main-lane queueing patterns. The calibration procedures used were clearly subjective in nature. However, because the primary concern was the differential effects of the design configurations rather than the performance of a particular system, the calibration procedures employed seemed consistent with the level of precision desired.

Freeway capacity was found to be a particularly sensitive parameter in the calibration process. Even modest changes in capacity produced substantial differences between simulated and observed conditions.

The merging analysis subroutine of the model posed some initial difficulties during the calibration process. For example, the merging analysis option should be engaged only when theoretical ramp capacities are used. The merging analysis subroutine then simulates ramp operations by metering ramp volumes. If the merging analysis option is engaged when measured volumes are used, the metering effect of the merging analysis subroutine will tend to inflate the ramp delay values.

### Summary of Results

The design year (1995) simulations were performed for two traffic growth scenarios. A low-growth scenario assumed a 3 percent annual increase in freeway traffic demand, and a high-growth (or worst-case) scenario assumed the existence of a base year (1981) freeway latent travel demand of 40 percent (3). Tables 2 and 3 give summaries of the key operational measures of effectiveness developed from the simulations. It should be noted that the measures of effectiveness given in Tables 2 and 3 are based on

TABLE 2 Summary of Simulated Measures of Effectiveness Assuming Existence of Freeway Latent Travel Demand *(3,4)*

Analysis Period: 6 a.m. to 9:30 a.m.

| Alternative | Traffic Year | Freeway Travel Time | | Total Travel Time (Incl. ramp delay) | | Total Travel Distance | | Average Vehicle Speed (mph) | Gasoline Consumption (gallons) |
|---|---|---|---|---|---|---|---|---|---|
| | | Veh-Hr. | Pass-Hr. | Veh-Hr. | Pass-Hr. | Veh-Mi. | Pass-Mi. | | |
| Do Nothing | 1981 | 4,400 | 6,000 | 4,400 | 6,000 | 190,600 | 260,300 | 43 | 11,700 |
| | 1995 | 9,900 | 13,500 | 61,100 | 83,400 | 186,700 | 225,100 | 20 | 43,400 |
| Stack Ramps | 1995 | 8,000 | 10,900 | 55,500 | 75,600 | 183,300 | 250,300 | 23 | 40,900 |
| Add One Lane | 1995 | 10,900 | 14,900 | 46,900 | 62,400 | 270,600 | 369,700 | 26 | 39,800 |
| Add Shoulder Lane | 1995 | 9,300 | 12,800 | 52,900 | 72,100 | 187,700 | 256,400 | 20 | 39,400 |
| Add Two Lanes | 1995 | 9,900 | 13,500 | 37,600 | 48,200 | 328,000 | 448,100 | 35 | 37,500 |

TABLE 3 Summary of Simulated Measures of Effectiveness Assuming No Freeway Latent Travel Demand *(3,4)*

Analysis Period: 6 a.m. to 9:30 a.m.

| Alternative | Traffic Year | Freeway Travel Time | | Total Travel Time (Incl. ramp delay) | | Total Travel Distance | | Average Vehicle Speed (mph) | Gasoline Consumption (gallons) |
|---|---|---|---|---|---|---|---|---|---|
| | | Veh-Hr. | Pass-Hr. | Veh-Hr. | Pass-Hr. | Veh-Mi. | Pass-Mi. | | |
| Do Nothing | 1981 | 4,400 | 6,000 | 4,400 | 6,000 | 190,600 | 260,300 | 43 | 11,700 |
| | 1995 | 9,500 | 12,900 | 33,500 | 45,700 | 185,500 | 253,500 | 21 | 27,600 |
| Stack Ramps | 1995 | 7,700 | 10,500 | 31,300 | 42,600 | 181,200 | 247,500 | 25 | 26,800 |
| Add One Lane | 1995 | 9,400 | 12,800 | 19,800 | 25,900 | 273,600 | 373,900 | 33 | 24,100 |
| Add Shoulder Lane | 1995 | 9,100 | 12,400 | 29,500 | 40,100 | 182,200 | 248,900 | 21 | 25,600 |
| Add Two Lanes | 1995 | 5,000 | 6,800 | 15,100 | 18,900 | 279,000 | 381,100 | 56 | 23,500 |

information from the simulation summary tables and, as such, refer to the entire length of the freeway. Conditions on individual subsections of the freeway may vary considerably from these system averages.

To get a feel for the potential localized effects of the system configurations evaluated, the queueing contours output by FREQ6 were examined. Figure 2 shows a summary of these contours for the "with latent demand" scenario. The queueing contours depict those freeway subsections operating at or below 35 mph. As shown in Figure 2, the "stacked ramps" alternative and the "add two lanes" alternative could have significant clearing effects on those sections of the freeway downstream of the I-610 interchange. Note, however, that only the "add two lanes" alternative appears to have the potential to produce any substantial improvement in system operating speeds (see Table 3). Consequently, in terms of the study objective of maximizing person throughput, the "add two lanes" alternative appears to be the best of the improvements evaluated.

## CONCLUSIONS

Given the growth rates and travel patterns that characterize the freeway corridor, none of the improvements evaluated (with the possible exception of the "add two lanes" alternative) appears capable of doing much to alleviate the peak-period congestion problems that plague the corridor. Because of their propensity to attract traffic from other routes and to generate additional (or at least previously unserved) vehicle trips, improvements directed at the supply side of the problem do not appear, in this case, to be particularly effective. The simulation results suggest that operational improvements or demand management strategies that address the problems of main-lane congestion by diverting traffic to alternate routes or other travel modes (e.g., high-occupancy vehicles) may be more productive.

Based on the experience gained using the FREQ6 model it is concluded that the model can be an effective tool for comparing freeway improvements. The measures of effectiveness output by the program are extensive and provide the analyst a good deal of flexibility in selecting an evaluation scheme. Though the calibration process can be tedious, the macroscopic nature of the program requires a minimum amount of input data and computer time. For the simulations reported in this paper, the simulation of 3.5 hr of clock time (14 time segments) required only 8 sec of central processing unit time at a cost of about $2.50 per run. Thus, when properly calibrated, the FREQ6 model can be a highly effective and economical tool for studying the dynamic response of a freeway to a variety of input specifications.

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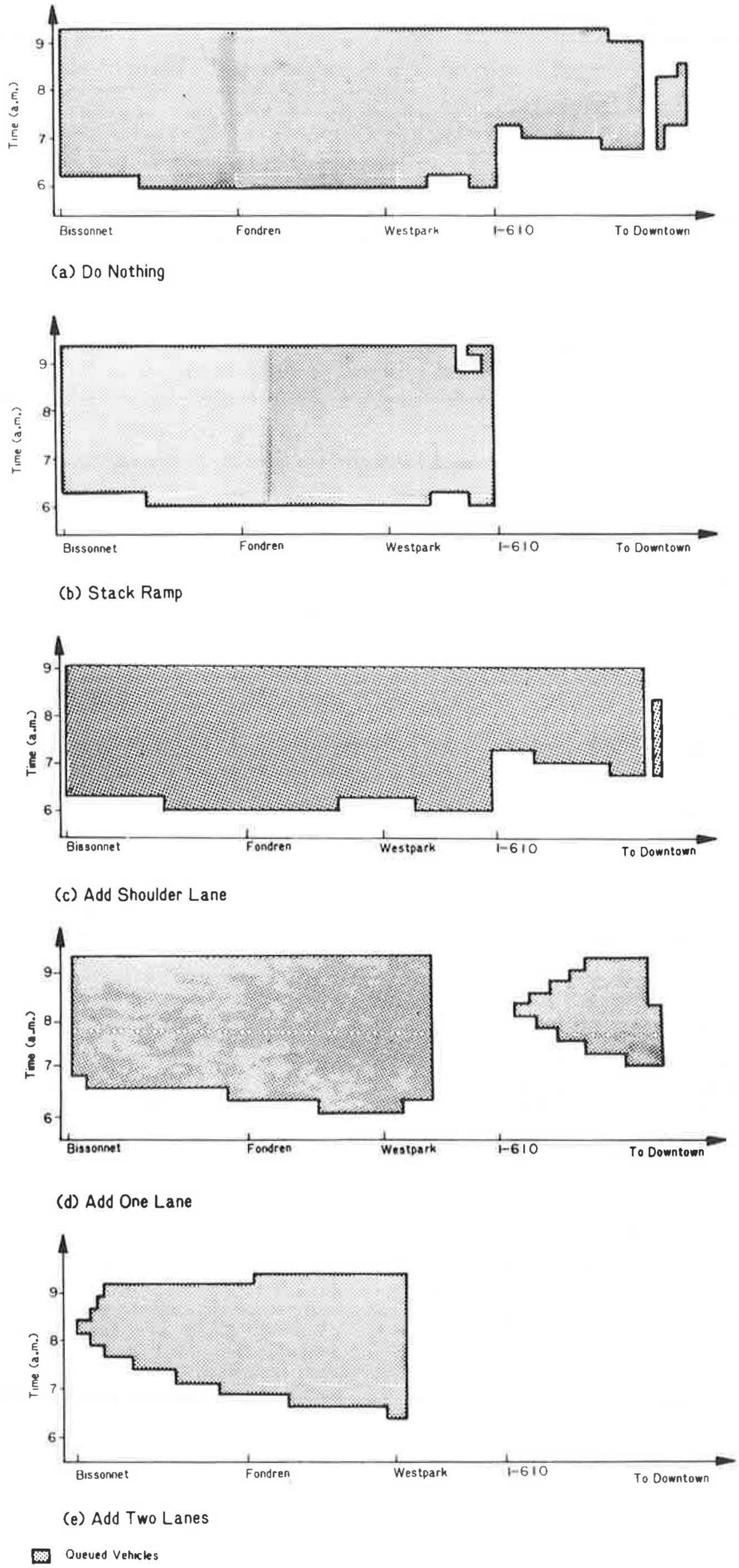


**FIGURE 2 Simulated 1995 a.m. peak-period queueing contours (with latent demand).**

REFERENCES

1. R.W. Holder, D.L. Christiansen, and C.A. Fuhs. Houston Corridor Study. Final Report. Texas Transportation Institute, Texas A&M University, College Station, 1979.
2. P.P. Jovanis, W.-K. Yip, and A.D. May. FREQ6PE--A Freeway Priority Entry Control Simulation Model. Research Report UCB-ITS-RR-78-9. Institute of Transportation Studies, University of California, Berkeley, 1978.
3. R.W. Stokes, J.M. Mounce, D.E. Morris, and R.L. Peterson. Simulation Analyses of Proposed Improvements for the Southwest Freeway (US-59), Houston, Part 1: Long-Term, Capital-Intensive Improvements. Final Report. Texas Transportation Institute, Texas A&M University, College Station, 1982.
4. R.W. Stokes, D.E. Morris, and W.R. McCasland. Simulation Analyses of Proposed Improvements for the Southwest Freeway (US-59), Houston, Part 2: Demand Management/Operational Improvements. Texas Transportation Institute, Texas A&M University, College Station, Jan. 1983.

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# Development and Application of a Macroscopic Model for Rural Highways

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ABSTRACT

The development of a macroscopic computer simulation model is presented. The simulation model, RURAL1, calculates traffic performance given road supply (geometrics) and demand (traffic) information. The model can analyze four types of subsections: freeway, multilane, two-lane, and passing-lane. To perform the simulation, the roadway must first be divided into subsections; users can specify up to 100 subsections. Subsection boundaries are established on the basis of changes in road geometrics, or traffic demand characteristics, or both. RURAL1 calculates traffic performance measures, such as average speed, travel time, and vehicle delay, on a directional basis for each subsection and summarizes performance results for the entire roadway section. The simulation model was applied to an actual field site where the existing condition was evaluated against two additional cases.

In recent years road maintenance budgets have increased substantially, affecting the availability of funding for new construction. Thus, state transportation agencies have been looking for new ways of managing the existing transportation system more effectively, using an approach called transportation system management (TSM). This approach is now being applied to the rural road system.

New techniques are needed to evaluate the cost-effectiveness of rural road improvements and to provide planners and decision makers with more accurate information on which to base their decisions. Sophisticated computer models, all microscopic, have been developed to study traffic operations on rural roads. Although these models offer great capabilities for analyzing traffic behavior, their applications are limited. Particularly important is the restriction these models impose on the size of the road section that can be simulated. Because of their simpler structure and logic, macroscopic models can easily be used to study longer sections of roadway where several improvements are to be implemented. However, as a result of their simplified logic, macroscopic models offer less detail and precision in performance and measures of effectiveness (MOEs) than microscopic models do and should be treated as a supplement to microscopic models rather than as a replacement.

Historically, macroscopic models have been derived after the development of, and with the use of, microscopic models. In freeway corridors, for example, the development of the macroscopic FREQ model followed early microscopic models used in the analysis and study of freeway operations. The need to consider additional impacts and to study more control strategies played an important role in the creation of FREQ. Another example is TRANSYT, a macroscopic model for the analysis and optimization