Vehicle Tracking Simulation in Low-Volume Road Design

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Accurate determination of the horizontal surface geometry of low-volume roads in steep, difficult terrain is a critical design element. The accurate assessment of this element is directly related to the efficiency of road construction cost and vehicle operations and safety. Because traditional methods used to determine the minimum required, horizontal road surface width were inadequate, a scale model drafting device, the Drafting Vehicle Simulator, was developed. This device was developed and implemented by the USDA Forest Service, Pacific Northwest Region. The application of this design aid has yielded considerable cost savings on specific project designs when compared to traditional design procedures. The Drafting Vehicle Simulator accurately simulates tire-mounted, Ackerman-steered, and nonarticulated vehicles traveling at low speeds. Single-unit, multi-unit, and special vehicles can be modeled. The simulator can be applied to the design analysis of horizontal road geometry, such as tracking through simple and compound curves, intersections, and approaches to road structures, and backing up and turning around. The Drafting Vehicle Simulator is a low-cost, easy-to-operate, and portable low-volume road design aid that yields accurate results. It has applications for the design of civilian and military low-volume roads and analysis of existing roads for vehicle passage.

Thousands of miles of low-volume roads are constructed worldwide each year. These transportation facilities are required to accommodate many different types of vehicles. Efficient road design is necessary to minimize construction cost and provide safe, adequate transportation facilities. Road construction costs are minimized when a minimum road design geometry is applied to accommodate design vehicles safely and efficiently. In order to meet the challenges of increasing forest road costs, the USDA Forest Service implemented a national program in 1981 to reduce the agency's road construction costs. One major objective of this program was to develop minimum geometric design standards for low-volume forest roads. To help meet this objective, a scale model, the Drafting Vehicle Simulator (DVS), was developed and implemented for use in national forests in the Pacific Northwest region. This device is a road design aid that is used to analyze the tracking characteristics of various design vehicles that operate on forest roads to determine the minimum required, design road surface width geometry.

The following three major objectives were achieved in the development and implementation of the DVS:

- Accurate vehicle tracking simulation of a wide range of large vehicles that use forest roads in the Pacific Northwest,
- Simple, efficient operating procedures with cost-effective results, and
- Low-cost equipment procurement and maintenance.

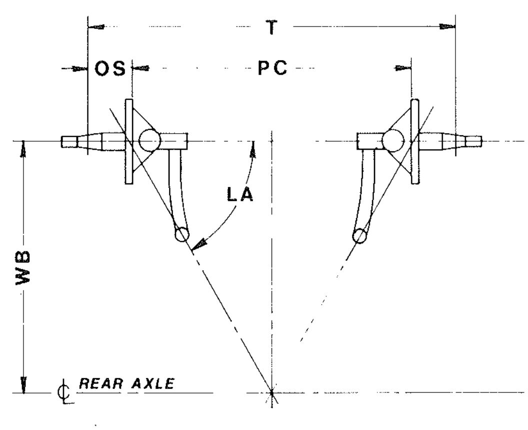
The DVS has several advantages to existing scale and mathematical models used to estimate vehicle tracking characteristics. These advantages are summarized in Table 1.

The DVS is fabricated from brass and stainless steel key stock. All parts are machined to tolerances of ± 0.001 in. The steering mechanism and all wheels are constructed with precision ball bearing sets. The tires are rubber O-rings. It is designed to operate at a minimum scale at which 1 in equals 10 ft.

The DVS accurately simulates and plots vehicle tire tracking of a nonarticulated, Ackerman-steered (Figure 1), and tire-mounted vehicle traveling at low speeds. Excellent tracking correlation was obtained with the tracking data developed by the California Department of Transportation using a Tractrix Integrator, which is a scale model of a tractor-trailer unit.

The DVS and accessory components are stored in a water-tight, crush-proof carrying case to facilitate field transport and storage (Figure 2). The tracking characteristics of the following vehicles are easily simulated:

- Any single-unit vehicle. One example is a large log yarder with a forward down-rigged tower (Figure 3).
- Highway tractor-trailer (Figure 4).
- Tractor-jeep-trailer (Figure 5).
- Log truck (Figure 6).



T Track of tires at ground

PC Distance between knuckle pivot centers (True)

O.S. Offset, pivot center to track of tire on ground

W.B. Wheelbase

La Cross steering lever angle from axle centerline (True)

FIGURE 1 Basic Ackerman steering arrangement.

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TABLE 1 COMPARISON OF FOUR VEHICLE TRACKING SIMULATION MODELS

	Computer Model	Scale Drafting Models		
Simulated Parameters	USFS Tractrix Equations	U.S. Army Vee-Tran	USFS DVS	California DOT Tractrix Integrator
Maximum steering cramp angle?	No	No	Yes	No
Backup and turning maneuver?	No	No	Yes	Yes
Track through compound curves?	No	No	Yes	Yes
Simulate various standard highway units?	No	Yes	Yes	No
Simulate log yarding equipment?	No	No	Yes	Yes
Simulate a log truck?	No	No	Yes	No

FIGURE 2 Drafting vehicle simulator and accessories in storage case.

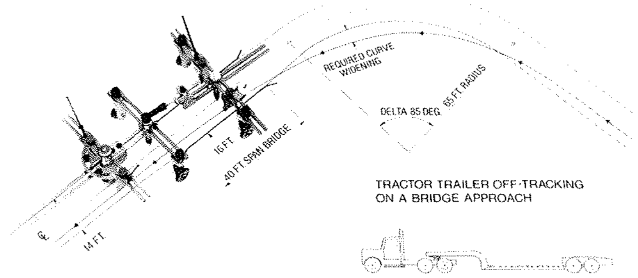


FIGURE 4 Tracking plot of a highway tractor-trailer traversing a simple curve and bridge in one direction.

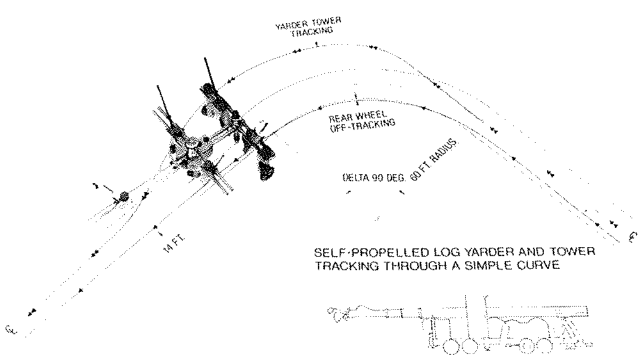


FIGURE 3 Tracking plot of a large Pacific Northwest log yarder and tower traversing a simple curve in one direction.

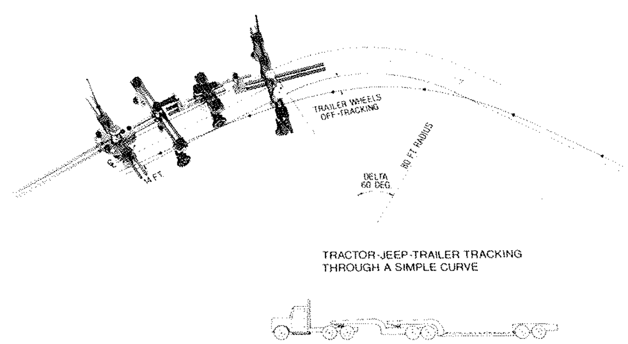


FIGURE 5 Tractor-jeep-trailer traversing a simple curve in one direction.

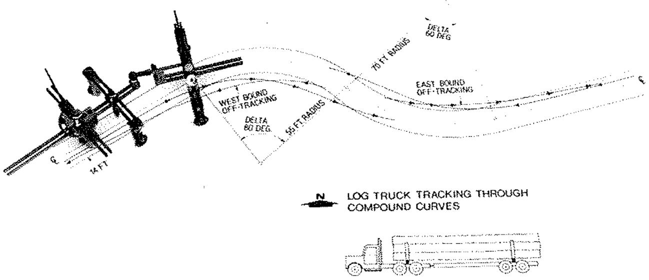
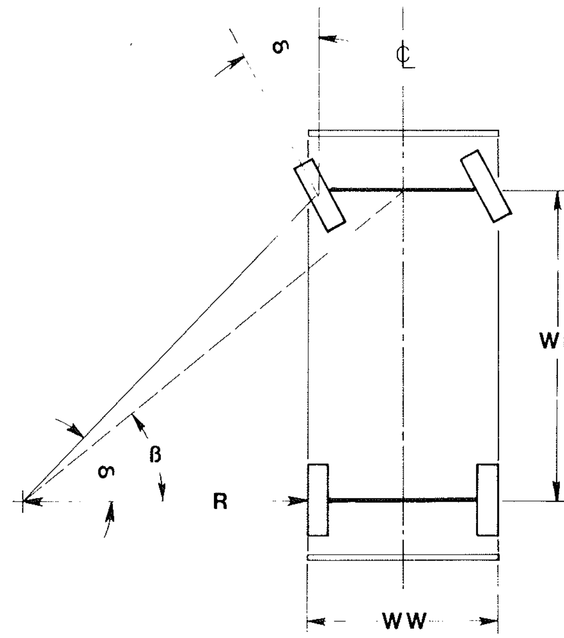


FIGURE 6 Log truck traversing a reverse and compound curve in two directions.

The DVS can be adjusted to a particular vehicle scale with hand-adjusted thumb screws and an Allen screwdriver. The steering unit's cramp angle, button-head stops can be adjusted in 5° increments from 5 to 45° left and right (Figure 7). The DVS was designed with a tricycle steering arrangement. In order to simulate Ackerman steering, the maximum Ackerman steering cramp angle must be recomputed and the DVS cramp angle stops must be adjusted accordingly (Figure 8). A 6-in plastic scale with increments of 10 to 1 in is provided for wheel base and vehicle overhang adjustments. Ball-point pens are used to plot wheel and vehicle overhang tracking. Out-to-out vehicle wheel widths are most easily scaled by plotting these dimensions on 10- to 1-in engineering paper and making appropriate adjustments (Figure 9).

The DVS is easily operated by moving the model through a section of road and plotting the surface width on drafting paper to a scale at which 1 in equals 10 ft (2.54 cm equals 3.05 m). The unit is propelled and steered by the steering knob on the steering unit. The road designer simulates actual steering through curves as if he was driving the simulated vehicle.



WW Out to out wheel width

WB wheel base

β Vehicle maximum steering cramp angle

σ D.V.S. simulated maximum steering cramp angle

$$\text{Tan}^{-1} \frac{WB}{R \quad \frac{WW}{2}}$$

FIGURE 8 DVS steering cramp angle computations.

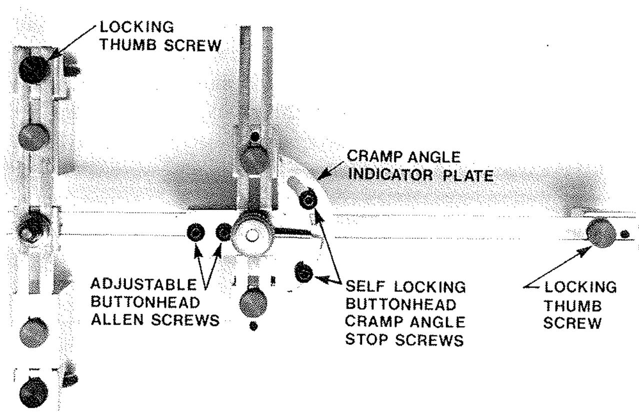


FIGURE 7 DVS steering unit scale adjustments.

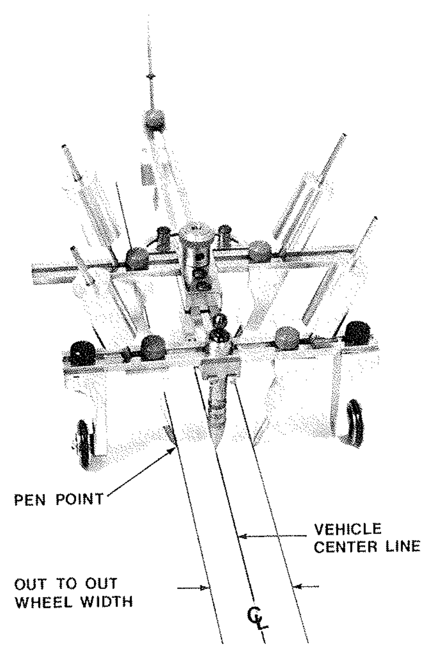


FIGURE 9 DVS wheel width adjustment.

The following are examples of DVS road design project applications:

- Vehicle tracking characteristics through simple and compound curves to determine minimum required curve widening,
- Restricted operating and parking spaces for tractor-trailer units,
- Critical bridge approach designs,
- Minimum parking facility design required for large tour buses,
- Empty log truck turn-around designs,
- Waterfront log dump design,
- Analysis of log sweep of tree length logs on a log truck on curves and in intersections,
- Large log yarder wheel tracking and tower sweep to determine minimum road width and cut bank design, and
- Required curve widening for design of roadway retaining walls.

The procurement cost of the DVS was a prime consideration in its development and design. The cost of the entire unit, including the carrying case, was $495.00 in 1985.

The DVS has proved to be a cost-effective design aid in the analysis of vehicle tracking in low-volume roads. Its application covers a wide range of practical vehicle tracking design situations that other scale and computer models do not effectively address. The operating procedures of the DVS are easily learned and rapidly applied. A road design engineer can be taught to use the DVS in 1 hour. The application of this tool in road design yields considerable savings in road construction costs when compared to the traditional design analysis of horizontal road geometry.

Development of New Design and Construction Guidelines for Low-Volume Road Bridges

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Low-volume road bridges in the United States are currently designed with the aid of AASHTO Standard Specifications for Highway Bridges. These specifications were primarily developed for high-volume urban and interstate highways. The design and construction of low-volume road bridges is therefore expensive. It is obvious from the current design and funding pattern in the United States that available funds are not sufficient to rehabilitate or replace all the deficient low-volume road bridges. A systematic investigation is therefore being performed to study the cost-effective use of various super- and substructural systems and miscellaneous bridge components to better use available funds. The unique characteristics of a low-volume road bridge are defined in this paper as a function of speed limits, average daily traffic, gross vehicle weight, and bridge width. The standard highway bridge specifications of the United States and other countries are reviewed and modifications to certain specifications and elimination of others are proposed. Feasible low-volume bridge components can be selected by eliminating inappropriate alternates and comparing the advantages and disadvantages of the remaining super- and substructural bridge systems. Concrete, steel, and timber structural components are reviewed, and design and cost scenarios that were developed in this study are highlighted. In order to recommend the effective use of limited available funds for bridge replacement programs, a value engineering approach was adopted to research the cost-effectiveness of various bridge components; types of materials used in the construction of low-volume road bridges; and current specifications for design, construction, maintenance, and rehabilitation.

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Over the past several decades, about a trillion dollars have been invested in the highway system of the United States. However, a massive infusion of additional funds is required to maintain, rehabilitate, and replace the rapidly deteriorating highway system. For example, it is estimated that $48.9 billion in 1982 dollars will be needed to repair or replace 253,196 of about 600,000 bridges that were classified as deficient at the end of